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ADVANCED MISSION AND INFORMATION STUDIES

ELEVENTH ANNUAL REPORT

1 June 1984 to 31 May 1985

by

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for

Solar System Exploration Division
Office of Space Science and Applications
NASA Headquarters
Washington, DC

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FOREWORD

This report summarizes the results of advanced studies and planning support by Science Applications International Corporation (SAIC) under Contract No. NASW-3622, Advanced Missions and Information Studies, for the Solar System Exploration Division, Code EL, of NASA Headquarters. In accordance with established contractual requirements, a detailed summary of the past year's work is provided in this annual report. The term of performance covered here is the 12-month period from 1 June 1984 through 31 May 1985. During this period, a total effort of 16,758 work-hours (105 work-months) was expended on the general support activities and seven study tasks. The total contract cost expenditure for this period of performance was $891,697.

Of the 16,758 work-hours total level of effort, productive technical labor was 15,592 work-hours and clerical labor was 1,166 work-hours. On the basis of the negotiated CPFF-LOE contract (16,256 productive direct labor hours plus or minus 5 percent), the performance actualized represents a level-of-effort underrun of 664 work-hours or 4.1 percent. The cumulative performance over the first three years of this contract is 3.2 percent under the negotiated productive level of effort.

Inquiries regarding further information on the contract results reported herein should be directed to the Project Manager, Mr. Alan Friedlander, at 312/885-6800.

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1. INTRODUCTION

Science Applications International Corporation (SAIC) participates in a program of advanced concepts studies and planning analysis for the Solar System Exploration Division, Code EL, NASA Headquarters. SAIC's charter is to perform preliminary analyses and assessments for Code EL planning activities. Specifically, the objective of this support is to ensure NASA of an adequate range of viable future planetary mission options so that its objective of solar system exploration can be pursued in an effective manner within the changing constraints of the U.S. Space Program. The nature of the work involved is quite diverse, ranging from fast-response items to pre-Phase A level mission studies. During the past contract year, a total of 18 SAIC staff members and one consultant contributed to the main technical effort. Table 1-1 presents a synopsis of these contributions.

The purpose of this report is to summarize the significant results generated under this Advanced Mission and Information Studies contract during the third year, 1 June 1984 through 31 May 1985, of a continuing contract. Progress reports on task efforts are presented at scheduled quarterly reviews. Task reports are prepared at the completion of each task and presentations of significant study results are given to a wide audience at NASA Headquarters, NASA centers, and at technical meetings. This report, therefore, is necessarily brief. Each of 11 contract task areas is presented in the next section. A brief description is given of the analyses performed along with key results and conclusions. The intention is to direct previously uninformed, but interested, readers to detailed documentation and to serve as a future reference to completed advanced studies. The final section of the report contains a bibliography of the reports and publications that have resulted from these task analyses.

SAIC is presently continuing this program of advanced studies for the Solar System Exploration Division under a twelve-month extension to this effort.

Table 1-1

1984-85 ADVANCED STUDIES - SUMMARY OF ACCOMPLISHMENTS (3RD CONTRACT YEAR)

• ADVANCED PLANNING TASKS	22 REPORTABLE ITEMS
• STUDY TASK REPORTS	7
• QUARTERLY REVIEWS	3
• CONFERENCE PAPERS	3
• ADVISORY COMMITTEE PARTICIPATION	SSEC, MO&IS SSEMC, TECHNOLOGY SUBCOMMITTEE, SENIOR PROGRAM REVIEW BOARD, NOAA/NASA
• SCIENCE/PLANNING COMMITTEE PRESENTATIONS	PLANETARY MANAGEMENT COUNCIL MO&IS SUMMER STUDY ACADEMY SUMMER STUDY SSEMC MEETINGS ESA/NASA JOINT STUDY TEAMS SSB TASK GROUP MEETING MARS STEERING COMMITTEE MEETING PSDSG RETREAT
• WORKSHOP MANAGEMENT/EDITING	PLANETARY DATA WORKSHOP
• GRAPHICS SUPPORT TO CODE EL	

2. TASK SUMMARIES

A total of 11 study task areas was addressed during the 12-month contract period. Nine of these are basically technical in nature while the last two represent added support activities for Code EL in special graphics and conference administration/planning. The task areas are:

1. Advanced Planning Activity
2. Cost Estimation Research and Applications
3. Planetary Missions Performance Handbooks
4. Inner Planets Mission Analysis (no activity this year)
5. Outer Planets Mission Analysis
6. Small Bodies Mission Analysis
7. Advanced Mission and Technology Concepts
8. Earth Science Mission Planning
9. Planetary Data System Planning
10. Graphics Support
11. Conference Support.

This section contains summaries of work performed in these task areas during the contract period. In several cases, a task area included specific and distinct subtasks which will be reported on within the general organization denoted above. The information contained in these summary descriptions is available in expanded, more detailed form through published task reports, presentation documents, and conference papers which are noted herein and listed in Section 3.

2.1 Advanced Planning Activity

The purpose of this task is to provide technical assistance to the Solar System Exploration Division of NASA Headquarters on planning activities which arise during the contract period. This type of advanced planning support is a traditional segment of the broader studies work which the staff at SAIC has performed for Code EL during all past contract periods. Subtasks within this activity range from straightforward exchanges of technical data by phone, through multi-page responses by mail or telecopier, to more extensive memo-

randa and presentations, and occasionally to complete status reports on subjects of particular interest. The level of effort per subtask can vary from as little as one man-hour to as much as several man-weeks. A total of 22 reportable advanced planning subtasks, performed during the 12 months of the contract period, is summarized here. Each of these was the subject of a written submission at the time of completion. Descriptive titles of these subtasks are tabulated in chronological order in Table 2-1. A brief summary of each of the subtasks is presented in the subsections which follow.

2.1.1 Summary of SAIC Advanced Studies Planning Activity

As part of an OSSA management review of advanced study programs in each division, SAIC was asked to provide a set of view-graphs which summarized three or four areas of study emphasis within our contract. Four view-graphs were prepared. Specific questions addressed were: (1) How does the mission or area of study relate to one or more science objectives of solar system exploration? (2) What are the technical objectives behind each of the major tasks of our contract support? and (3) How do the results of our studies reach the science community and how timely is the transmission of this information?

2.1.2 Cost Estimates of Selected Mariner Mark II Development Projects

The purpose of this subtask was to provide NASA Headquarters with an independent estimate of the costs of a set of Mariner Mark II (MMII) projects. The five-mission set consisted of the Comet Rendezvous/Asteroid Flyby (CRAF), Saturn Orbiter/Titan Probe (SOTP or Cassini), Uranus Flyby/Uranus Probe (UFUP), Mainbelt Asteroid Rendezvous (MBAR) and Saturn Flyby/Saturn Probe (SFSP). Spacecraft and mission descriptions were provided by JPL and probe definitions were provided by NASA/ARC. Cost estimates were generated for the development projects, which run through the Launch + 30 days milestone. The cost estimates ranged from a low of $244M for SFSP to a high of $335M for CRAF (FY 1984 dollars). CRAF cost estimates were generated for both the JPL Strawman Payload and the Science Working Group payload (including penetrator), and for both an all-NASA mission and one with German participation. An estimate for the cost of the ESA-provided probe was included in the SOTP mission. The major conclusion of this effort was that the initial MMII

Table 2-1

SUMMARY OF 1984-85 ADVANCED PLANNING ACTIVITIES

Subtask	Month	Subtask/Title
1	Jul 1984	Summary of SAIC Advanced Studies Planning Activity
2	Jul 1984	Cost Estimates of Selected Mariner Mark II Development Projects
3	Jul 1984	OSSA Budget Planning Support
4	Aug 1984	Ceres Round-Trip Trajectories
5	Aug 1984	Space Science Board Summer Study Planetary/Lunar Task Group Participation
6	Oct 1984	Discovery Capsule Entry Analysis at Titan
7	Oct 1984	Launch Vehicle Capture Diagram for Augmented Program Missions
8	Oct 1984	Launch Demand for Planetary Missions (1994-2006)
9	Jan 1985	Revised Cost Estimate for Giotto II Coma Sample Return Mission
10	Jan 1985	Impact of Giotto II on Planetary Observer Funding
11	Jan 1985	SSB Task Group Meetings, "Major Directions for Space Sciences: 1995-2015"
12	Feb 1985	MSFC OTV Configurations Performance Analysis
13	Feb 1985	Technology Requirements Writeup
14	Feb 1985	OSSA Budget Planning Support - Continued
15	Feb 1985	Comparison of Planetary Exploration FY85 and FY86 Budgets
16	Feb 1985	NASA Long-Range Program Plan: 1986-1990
17	Mar 1985	Graphical Representation of Solar System Exploration Accomplishments
18	Mar 1985	Comet Coma Sample Return Mission Opportunities

Table 2-1 (cont'd.)

SUMMARY OF 1984-85 ADVANCED PLANNING ACTIVITIES

Subtask	Month	Subtask/Title
19	Apr 1985	Comet Rendezvous Mission Opportunity/Performance Assessment
20	Apr 1985	3-D Perspectives of Planetary Exploration
21	May 1985	OSSA Budget Planning Analysis for SESAC Presentation
22	May 1985	Historical Trends in Ground Operations Development Costs

missions will not be able to meet the $300M (FY '84) cost guideline, but could meet a $335M guideline. However, assuming that the concepts of hardware commonality and spacecraft modularity remain valid, it appears that follow-on missions can meet the $300M cost guideline.

2.1.3 OSSA Budget Planning Support

A set of budget planning charts was generated for each division within OSSA based on the FY 1985 Congressional Budget runout. Each division-level chart showed projected new starts based on individual division plans. The new starts included CRAF (FY '86), Observers (FY '87), TOPEX (FY '86), ISTP (FY '87) and SIRTF (FY '88). Each division budget was shown as reaching a mature level of funding by the early-to-mid 1990's. Major undertakings such as AXAF (FY '88) and potential planetary augmentation missions were shown as Code E-level programs. It was determined that OSSA would need to sustain an average of nearly 3% real growth per year above the FY '85 level in order to reach the projected maturity levels of the 1990's.

2.1.4 Ceres Round-Trip Trajectories

In this subtask, SAIC provided Eagle Engineering, Inc. (EEI) with round-trip ballistic trajectory information to the asteroid Ceres. A Ceres sample return mission was then included as one of several planetary missions comprising the database for EEI's study of the impact of lunar and planetary missions on the Space Station. The baseline mission strategy was an October 1994 launch employing a dual Mars swingby to reduce outbound ΔV requirements, arriving at Ceres in May 1999. Following a 35-day stay time at Ceres, a direct return trajectory was used, for arrival at Earth in June 2000. (The best Mars swingby trajectory for the return leg allowed only a 200 m/sec ΔV savings over the direct return at the expense of over 700 days of flight time.) The total ΔV requirement for this mission was 13 km/sec, which represented the upper limit in energy requirements in the EEI parametric studies.

2.1.5 Space Science Board Summer Study Planetary/Lunar Task Group Participation

The Space Science Board of the National Research Council was requested by the NASA Administrator to undertake a long-range study of major directions for

space sciences in the 1995-2015 time frame. SAIC's participation in this first Summer Study included the presentation of several complete Core Program mission strategies including all encounters in order to assess the impact of future data on long-range program plans. Three options were explored which build upon the "Hard-Core" Program of VRM, MGCO, CRAF and Cassini. The three options were: (1) SSEC Core with Primitive Body Emphasis, (2) SSEC Core with Outer Planet Emphasis, and (3) SSEC Core with SEP. The interesting conclusion of this exercise was that the differences in the three options are not significant until the year 2000. For each strategy, a Flight Schedule Table and Encounter Summary Table were included. A total of 37 encounters are made assuming the Primitive Body Emphasis plan, compared to 36 in the Outer Planet Emphasis plan, whereas the SEP plan calls for 44 encounters due to the increased number of orbiter missions available with the SEP technology.

2.1.6 Discovery Capsule Entry Analysis at Titan

NASA acquired two General Electric Discovery entry capsules from the Air Force, and studies were initiated to determine their possible use in planetary missions. This analysis was performed to verify the Discovery capsule performance as a low-cost Titan probe option. A parametric analysis was conducted to determine the skip angle, the altitude at which Mach 2 occurs, and the maximum heating rate, as a function of capsule ballistic coefficient and entry speed. For a ballistic coefficient range of 160-330 kg/m^2 and entry speeds of 3-12 km/sec, the skip angle ranged between -27 and -33 degrees, the altitude at Mach 2 ranged from 143-170 km, and the maximum heating rate ranged between $1.2x10^5$ to $1.1x10^7$ w/cm^2. The same parametric analysis was performed at skip angles of -5 and -10 degrees.

2.1.7 Launch Vehicle Capture Diagram for Augmented Program Missions

A launch vehicle capture diagram in the injected mass vs. launch energy format was prepared for Code EL for augmentation-type missions. Representative Augmentation missions included Mars Sample Return, Mercury Orbiter/Lander, Comet Nucleus Sample Return (both direct and ΔVEGA options), Galilean Satellite Orbiter/Lander, Uranus and Neptune Orbiter/Probe Missions (both direct and Jupiter swingby trajectories for each) and a Titan Orbiter/Probe mission. Launch vehicle upper stages included in the analysis ranged from the

Shuttle/Centaur(G') to a stacked Orbital Transfer Vehicle (OTV) conceptual stage. Injection energy requirements ranged from a low of 9 $(km/sec)^2$ for the MSR to a high of 149 $(km/sec)^2$ for a direct ballistic trajectory to Uranus. Injected mass requirements ranged from a low of 1700 kg for the Titan mission using aerocapture to a high of 16,500 kg for the MSR mission performed without aerocapture at either Mars or Earth.

2.1.8 Launch Demand for Planetary Exploration (1994-2006)

An estimate of the launch demand for the list of Core Program missions from 1995 to the early 2000's was prepared for Code EL. The information was compiled into a single table which included mission name, launch date, launch energy (C_3), and the injected mass and volume requirements. The mission set included both Core Program and candidate Augmentation missions.

2.1.9 Revised Cost Estimate for Giotto II Coma Sample Return Mission

This subtask is related to a previous Advanced Planning Task (Subtask 6) as it, too, was a study of a concept to use one of the GE Discovery capsules obtained from the Air Force for planetary missions. A revised cost estimate for the Giotto II Coma Sample Return mission was generated based upon the following costing assumptions and guidelines: (1) the GE Discovery capsule, used for sample return to Earth, would be obtained free but modified for different types of reels, openings and seals; (2) the collector experiment is an all-new design; (3) a full-scale test program for the collector experiment reel-in operation is needed; (4) ESA provides the spare Giotto spacecraft with minor modifications, added hydrazine tanks, data memory and Halley experiments; and (5) the U.S. provides hardware integration, mission design and launch support. A cost estimate of $61M (FY '84) was made, including mission operations for a one-year round-trip flight time.

2.1.10 Impact of Giotto II on Planetary Observer Funding

A comet coma sample return based on the Giotto II/Discovery capsule would be developed as a Planetary Observer-class mission. A budget analysis was performed to determine the impact of this mission on the Observer mission set. Assuming an FY '86 new start for Giotto II and that the $61M (FY '84) estimate

from the previous subtask is correct, it was determined that the next Observer mission, Lunar Geoscience Orbiter (LGO), could be started in FY '89 with a launch in 1993. The Giotto II mission would not have a significant impact on the overall Observer funding profile.

2.1.11 SSB Task Group Meetings, "Major Directions for Space Sciences: 1995-2015"

The task groups of the SSB Summer Study held at Woods Hole (Subtask 5) held follow-up meetings. SAIC was asked to participate in these meetings. One contribution involved a discussion of requirements for a Jupiter Magnetosphere/Polar Orbiter mission.

2.1.12 MSFC OTV Configurations Performance Analysis

Several upper stage propulsion systems based upon recent space-based OTV studies at MSFC were proposed for increasing launch capability. The concepts were based upon both 2- and 4-tank OTV configurations and both all-chemical and aerobraked return to low-Earth Orbit (LEO). An advanced engine with 482.5 sec I_{SP} and 15,000 lb_f thrust was assumed. Three stacked configurations were analyzed: (1) OTV(4-R)/TOS; (2) OTV(4-R)/OTV(2-R); and (3) OTV(4-R)/OTV(2-E). "TOS" stands for the conceptual Transfer Orbit Stage, "R" indicates aerobraked return of the OTV, and "E" indicates an expendable OTV. The analysis was performed using finite burns for all maneuvers. Curves of injected mass capability versus launch energy were generated for each configuration. Compared to the Shuttle/Centaur(G') curve, Configurations 1 and 2 are superior up to a C_3 of approximately 80 $(km/sec)^2$ while Configuration 3 is superior even to fully-loaded stacked Centaurs for all values of C_3.

2.1.13 Technology Requirements Write-up

SAIC was asked to provide brief discussions of five technology developments required for exploration of the outer planets and their satellites. These discussions would provide background material for Part 2 of the Final Report of the Solar System Exploration Committee. The five technological developments are: (1) atmospheric balloons for intensive exploration of Titan; (2) high-pressure atmospheric probes for second-generation probes at Jupiter; (3) radiation-hardened systems for extended missions within the inner

magnetosphere of Jupiter; (4) low-temperature systems for missions operating in extremely cold environments; and (5) autonomous operation and robotics to help mitigate the effects of long communication times between Earth and the outer planets.

2.1.14 OSSA Budget Planning Support - Continued

As a continuation of the support provided in Subtask 3, a revised set of division-level budget planning charts was generated. The revised charts carried the analysis only through FY 1990 and were based upon a new set of potential project start dates. The new project starts were: CRAF, TOPEX, ISTP, GP-B and AXAF in FY '87; Planetary Observers in FY '88; and Cassini, GRM and SIRTF in FY '89.

2.1.15 Comparison of Planetary Exploration FY '85 and FY '86 Budgets

Two budget planning charts were prepared for Code EL. The first chart used the FY 1985 Budget Runout while the second used the FY 1986 Budget Runout. The new starts included on each chart were CRAF (FY '87), Planetary Observers (FY '88) and Cassini (FY '90). Comparison of the two charts showed that the runout plus new start projection based on the FY '86 budget was slightly lower than that based on the FY '85 budget.

2.1.16 NASA Long-Range Program Plan: 1986-1990

SAIC contributed to the updating and editing of Section C. Exploration of the Solar System as part of the Space Science and Applications Plan. The contents of this section include: (1) Strategy - synopsis of the SSEC recommendations; (2) Current Program - descriptions of Pioneers through MGCO; (3) New Initiatives - descriptions of CRAF through CAESAR; (4) Program Status (projected) as of 1990; (5) Possible Initiatives - extension of the Core Program and potential Augmentation missions for inner planets, small bodies and outer planets; (6) New Technologies - requirements for Augmentation missions in the areas of advanced propulsion, aerocapture, *in situ* propellant production, automation and robotics, and sample recovery; and (7) Space Station Capabilities - discussion of possible support provided to planetary science goals by the Space Station.

2.1.17 Graphical Representation of Solar System Exploration Accomplishments

SAIC was asked to assist Code EL in developing a new graphical format as a summary presentation of accomplishments in solar system exploration. Solar system target body and time relative to 1960 were used as the independent axes; a measure of past and projected achievements through 2010 constituted the third dimension. Two proposed formats were submitted for consideration. The first was in the form of a fan-shaped diagram with time as the radial axis. Accomplishments at each target were measured as an increasingly darker gray scale. The second format was a three-dimensional orthogonal projection. Accomplishments at each target were shown as the cumulative sum of a subjective measure of knowledge gained from each past and future mission.

2.1.18 Comet Coma Sample Return Mission Opportunities

A presentation was made to the ESA/NASA Primitive Body Study Subgroup on Comet Coma Sample Return. The topic of the presentation was a discussion of mission opportunities which satisfy a set of mission design constraints. The constraints were: launch opportunities between 1988 and 1996; $C_3 \leq 50$ $(km/sec)^2$; $V_{enc} \leq 15$ km/sec; and $R_{enc} \leq 1.6$ AU. A total of 44 opportunities to 25 known comets was found which satisfies these constraints. The possibility of a coma sample return mission to a new comet was also presented. Results of a detailed statistical analysis implied that there would be an 80% probability of an acceptable launch opportunity occurring within 12 months of the mission launch readiness, and 95% within 24 months.

2.1.19 Comet Rendezvous Mission Opportunity/Performance Assessment

The Comet Rendezvous/Asteroid Flyby (CRAF) mission is scheduled for an FY 1987 new start. The baseline mission has a March 1991 launch to Wild 2 with a July 1991 launch to Kopff as a fallback option. A delay in the project new start may cause the launch date to slip beyond 1991. This analysis showed that after 1991 the only (marginal) opportunities using a direct flight mode are to Tempel 2 in 1994 and Tempel 1 in 1995. However, seven opportunities were identified in the 1992-94 launch time period using a ΔVEGA flight mode. This would require upgrading the CRAF spacecraft to a four-tank propulsion system, but would also yield adequate mass margins.

2.1.20 3-D Perspectives of Planetary Exploration

This subtask was a continuation of the work done under Subtask 17. Code EL requested variations in the perspective angle of the three-dimensional orthogonal projection developed earlier.

2.1.21 OSSA Budget Planning Analysis for SESAC Presentation

A presentation was made to the SESAC Planetary Subgroup of the budget planning charts developed previously under Subtask 14. The charts were updated to reflect revised program plans. In addition, a set of overlay charts in waterfall format was developed to display direct comparisons of the individual divisions' projected budgets.

2.1.22 Historical Trends in Ground Operations Development Costs

At the request of Code EL, the SAIC Planetary Program Cost Database was examined to assess past development costs for ground operations. Cost data from five projects were examined: Mariner Mars 1971, Viking Lander, Viking Orbiter, Voyager and Pioneer Venus. It was found that, for these five projects, the average cost through launch + 30 days to develop the ground system and software was approximately 10% of the cost to develop the mission flight hardware, with a standard deviation of less than 1%.

2.2 Cost Estimation Research and Applications

Cost estimation analysis has been an ongoing Advanced Mission and Information Studies support task for 11 years. The objective of this task is the development and implementation of a methodology for predicting costs of future lunar and planetary flight programs, for the purpose of providing reasonably accurate cost estimates based on pre-Phase A study definitions to key advanced planning activities within the Solar System Exploration Division. A flight project cost estimation model has been in existence at SAIC for the past ten years as a result of this task effort, and has been regularly improved and expanded in scope of application as a result of this ongoing

research. The nature of the work falls into three general subtasks:

1. Flight Program Data Collection
2. Modeling Analysis
3. Cost Prediction and Analysis.

Work is performed in all three subtask areas each year. The level of effort expended on data collection has stabilized during the past several years with three to four flight projects being tracked at any given time. Since the last revision of the model algorithms, more emphasis has been placed on applications than on modeling.

Flight Program Data Collection. Since data collection began more than 11 years ago, every effort has been made to incorporate all relevant lunar and planetary flight program data into the model. Direct labor, burden, materials and miscellaneous costs are tracked on every element of each program. These data are then reduced into new categories consistent with the modeling algorithms used in the cost model.

During the 1984-85 contract period new data were collected on Voyager, Pioneer Venus, Galileo Orbiter and Galileo Probe. Table 2-2 presents the current status of the cost database. Program costs are segregated into development project (i.e., costs incurred through launch + 30 days) and flight project costs to facilitate the modeling procedure, and the data collection status is indicated for each. Table 2-2 also indicates the general extent to which data from each program were used in revising the development project portion of the cost model.

Modeling Analysis. Development of an analytical cost spreading model was completed during the past contract period. The purpose of this model is to transform a development project cost estimate into annual funding levels given the project new start date and the mission launch date. In the past, funding levels have usually been estimated by analogy to past projects. This approach is limited, however, since the past and proposed projects may not be sufficiently similar in scope, complexity or duration. Conversely, an analytical

Table 2-2

COST MODEL DATABASE STATUS

PROGRAM	DEVELOPMENT PROJECT (TO L+30 DAYS)	FLIGHT PROJECT (POST L+30 DAYS)	USE IN MODEL REVISION (DEVELOPMENT PROJECT)
MARINER '64	C	C	PARTIAL
SURVEYOR	C	C	PARTIAL
LUNAR ORBITER	C	C	PARTIAL
MARINER '69	C	C	TOTAL
MARINER '71	C	C	TOTAL
PIONEER JUPITER/SATURN	C	C	TOTAL
MARINER '73	C	C	NOT USED
VIKING LANDER	C	C	TOTAL
VIKING ORBITER	C	C	TOTAL
VOYAGER	C	I	TOTAL
PIONEER VENUS	C	I	TOTAL
GALILEO ORBITER	I	X	FUTURE
GALILEO PROBE	I	X	FUTURE
VENUS RADAR MAPPER	I	X	FUTURE

C: COMPLETE
I: IN PROGRESS
X: NO DATA YET

model could provide a more flexible yet consistent method for estimating funding levels.

Historical funding data from three planetary development projects (Mariner Venus/Mercury, Viking Orbiter and Voyager) were used in combination with project funding curves obtained from Goddard Space Flight Center to develop the cost spreading algorithms. The fundamental algorithm is based on a distribution function known as the logistic function. The parameters of the logistic function are obtained from a set of curve fits to the historical data called the Duration and Shaping Functions. Inputs to the model consist of the estimated cost and duration of the development project, and an a priori estimate of the funding level in the first year of the project. Table 2-3 summarizes the cost spread model and the computational steps in its use.

Applications. Applications of the cost model have continued to increase. During the past contract period the model was used extensively in support of advanced planning activities by the Solar System Exploration Division and in support of other contract tasks. These activities included Mariner Mark II cost analyses and cost estimates for Mars Sample Return mission options. Results from these and other efforts are reported under the tasks for which they were performed.

Mass Estimation Program Development. For the past two years, SAIC and JPL have been involved in a joint project to modify the SDCM/IDEAS program in order to produce a version of the program which can be used for planetary spacecraft. In order to achieve this objective, it is necessary to incorporate new telecommunications routines into the program.

During the past year the new telecommunication routines have been completed at JPL and transferred to the PDP 11/44 at SAIC's Schaumburg, IL facility. Work is now in progress to incorporate these routines into the mass estimation program runstream.

It is expected that the telecommunications section of the program will be completed in the very near future and that a planetary type test case will be run and verified shortly thereafter.

Table 2-3

Summary of Cost Spreading Algorithm

Nomenclature:

C_y = annual funding, in dollars

P_y = annual funding levels, in percent

$P(q)$ = quarterly cumulative percentage funding

Input:

C_D = estimated total development cost, in dollars

FD = fiscal year date of project new start

LD = mission launch date

P_1 = estimate of first year funding level, in percent (if available)

Steps:

1) Obtain development project duration, in years:

$$Y = LD - FD$$

2) Evaluate Duration Function:

$$D = 0.840 + 3.106/Y$$

3) Evaluate Shaping Function, either:

$$S = 0.011047(P_1)^{1.1914} \ (Y)^{1.5202}$$

or alternately:

$$S = 5.506 - 0.712Y$$

4) Convert duration from years to integer quarters:

$$Q = 4Y \quad \text{(round up, if necessary)}$$

5) Evaluate the cumulative distribution:

$$P(q) = \frac{100SD^q}{100 + SD^q}$$

for quarters q = 4, 8, 12, ..., Q
and set P(Q) = 100%, P(0) = 0%

6) Determine annual funding levels from

$$P_y = P(q') - P(q'-4)$$

where $q' = 4y$ for $y = 1, 2, \ldots, \left[Q/4\right]$

7) Obtain annual funding from

$$C_y = C_D P_y$$

MO&IS Cost Model. The Solar System Exploration Committee (SSEC), as part of its charter to formulate a long-range program for planetary exploration, recommended a set of core missions over the decade of the 1990's constrained to a total budget of $300M per year (FY '84$). Within the $300M program, the SSEC recommended that $60M be allocated to Mission Operations and Data Analysis (MO&DA). Since the MO&DA budget in the late 1980's is projected to exceed $60M for several years, the SSEC organized a subcommittee to evaluate ways and methods of constraining the MO&DA costs to the $60M target in the 1990's.

A JPL study was initiated in 1984 to respond to the SSEC on MO&DA costs. The study goals were to define operations concepts that would operate the SSEC mission set at or below the $60M/year threshold, and to identify changes in current operations methods that would achieve this goal.

A major product of the JPL study was the development of a software model which estimates planetary mission operations costs. The program estimates all costs within the NASA MO&DA budget line item. These costs are defined to be all project costs from launch plus 30 days through the end of project, including multi-mission facility costs at the Flight Projects Support Office at JPL. In addition, the model estimates the cost of developing new concepts and capabilities for the multi-mission facility.

After preliminary results of the MOS cost model were presented in August 1984, NASA Code EL requested that SAIC obtain a copy of the model from JPL and make it operational at our Schaumburg, IL facility. Initial contact was made with J. Pieter DeVries, the MOS Cost Model Program Manager at JPL, in December 1984 and an information exchange meeting was held in January 1985. At this time, the team which had developed the program had been disbanded and Mr. DeVries was attempting the document the model. It was agreed that no software exchange would take place until sufficient documentation was in place. Documentation of the program proceeded slowly until mid-May when Mr. DeVries left the program to become Flight Science Office Manager for Voyager. At the end of this contract period, a replacement for Mr. DeVries had not yet been named.

2.3 Planetary Missions Performance Handbook

The primary goal of the Planetary Missions Performance Handbook (PMPH) series is to combine information available in several separate handbooks, and to supply analysts and program planners with a compilation of data that can be used directly in the preliminary stages of mission selection and design. The methodology of the PMPH series is to start with the raw trajectory data, make adjustments for launch windows, budget propellant for midcourse trajectory correction maneuvers, and compute velocity impulse requirements for orbit capture at the target. In short, the PMPH series combines the data from trajectory handbooks and propulsion system capability handbooks, and addresses the necessary computational chores to arrive at a final product, which is mission performance data in a form which is immediately useful in planning exercises.

During this contract period, work was completed on Volume I of the Handbook series. This volume covers missions to all five outer planets and the following selected satellites: Io, Europa, Ganymede, Callisto, Titan, and Triton. This 4th edition of Volume I -- Outer Planets includes the following additions and revisions:

- Extend launch opportunities through 2000 and beyond, in selected cases;
- Incorporate an updated set of launch vehicles into the mass delivery performance calculations;
- Add Neptune orbiter missions to the mission set;
- Add new flight modes for all targets, including nuclear electric propulsion (NEP) and solar electric propulsion (SEP) flight modes;
- Add orbiter missions to the Galilean satellites, Titan and Triton to the mission set;
- Add aerocapture technology for orbiter missions to the gaseous bodies, as well as flyby/atmospheric probe deployment missions; and
- Enhance the Handbook data reduction software.

The full scope of missions which are included in the new edition of Volume I is presented in Table 2-4. Launch opportunities for missions to the outer planets and their satellites extend through the 1990's and beyond, in some cases. Some of the new flight modes included in the 4th Edition are: NEP missions to all targets, Jupiter swingby SEEGA missions to Saturn, Uranus and Neptune, and Jupiter swingby ΔVEGA missions to Neptune.

Due to the large volume of information encompassed by the scope of missions and options considered, this edition of the Handbook was divided into two volumes. They are: the Main Volume, which includes detailed graphic and tabular data for missions to the outer planets; and the Supplement to Volume I, which includes these data for the Galilean satellites, Titan and Triton.

Within each of these volumes, basic transfer characteristics and payload performance results are presented in order of final target and mission type. Information for the outer planets is organized into these nine sections:

- Jupiter Flybys
- Jupiter Orbiters
- Saturn Flybys
- Saturn Orbiters
- Uranus Flybys
- Uranus Orbiters
- Neptune Flybys
- Neptune Orbiters
- Pluto Flybys.

Low-thrust data are included at the end of each orbiter section. Summary information regarding satellite missions is included within the orbiter section of the relevant outer planet. All detailed information on satellite orbiter missions may be found in the Supplement.

Detailed tabular and graphical data in the Supplement volume is organized into these three sections:

- Galilean Satellite Orbiters (Io, Europa, Ganymede, Callisto)
- Titan Orbiters
- Triton Orbiters.

Table 2-4

SCOPE OF VOLUME I, PMP HANDBOOK

TARGET	MISSION	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
		LAUNCH OPPORTUNITY (19xx, 20xx)																		
JUPITER/ GALILEAN SATELLITES	BALLISTIC FLYBY	X	X	X		X	X	X	X	X	X	X								
	BALLISTIC ORBITER	X	X	X		X	X	X	X	X	X	X								
	AVEGA ORBITER	X	X	X		X	X	X	X	X	X	X								
	SEEGA ORBITER																			
	NEP ORBITER																			
SATURN/ TITAN	BALLISTIC FLYBY	X	X	X	X	X	X	X	X	X	X	X								
	J/S BALLISTIC FLYBY								X	X	X									
	BALLISTIC ORBITER	X	X	X	X	X	X	X	X	X	X	X								
	J/S BALLISTIC ORBITER								X	X	X									
	AVEGA ORBITER	X	X	X	X	X	X	X	X	X	X	X								
	J/S AVEGA ORBITER				X	X	X	X	X											
	SEEGA ORBITER																			
	J/S SEEGA ORBITER					X	X	X	X											
	NEP ORBITER																			
URANUS	BALLISTIC FLYBY	X	X	X	X	X	X	X	X	X	X	X								
	J/U BALLISTIC FLYBY			X		X	X									X		X	X	X
	BALLISTIC ORBITER	X	X	X	X	X	X	X	X	X	X	X								
	J/U BALLISTIC ORBITER			X		X	X											X	X	X
	AVEGA ORBITER	X	X	X	X	X	X	X	X	X	X	X								
	J/U AVEGA ORBITER	X	X		X															
	SEEGA ORBITER																			
	J/U SEEGA ORBITER	X	X		X											X	X			
	NEP ORBITER																			
NEPTUNE/ TRITON	J/N BALLISTIC FLYBY			X		X	X								X	X		X	X	
	J/U/N BALLISTIC FLYBY		X	X		X														
	J/N BALLISTIC ORBITER			X		X	X									X		X	X	
	J/U/N BALLISTIC ORBITER		X	X		X														
	AVEGA ORBITER	X	X	X	X	X	X	X	X	X	X	X								
	J/N AVEGA ORBITER	X	X		X															
	SEEGA ORBITER																			
	J/N SEEGA ORBITER	X	X		X									X		X				
	NEP ORBITER																			
PLUTO	J/P BALLISTIC FLYBY	X	X	X										X	X	X		X		
	NEP ORBITER																			

Low-thrust data for the satellites are included at the end of each section.

Note that organization by final target means, for example, that J/N and J/U/N missions are to be found in the section titled "Neptune Orbiters". Each section is separately tabbed. Within these sections, a consistent pattern of organization is followed. It begins with an introductory subsection which briefly describes the mission alternatives, lists the launch opportunities and associated trajectory data, and presents a summary bar chart of payload performance senstivity to launch opportunity. These bar charts are included for both planet and satellite orbiters, where appropriate. The introductory section also includes representative performance plots for selected satellite orbiter opportunities, where applicable.

Launch opportunity-specific information follows the introductory remarks. The specific format and amount of data presented varies with the type of mission being considered. For flyby missions just one graph is presented for each launch opportunity. It presents the trade-off of net flyby payload with trip time to the target planet for each of five candidate launch vehicles. These launch vehicles are indicated on the plots by number. The launch vehicles corresponding to these numbers are as follows:

LV 1 - Shuttle/Centaur(G)
LV 2 - Shuttle/Centaur(G')
LV 3 - OOA/Centaur(G')
LV 4 - OOA/Centaur(G')/Centaur(G)
LV 5 - OTV(4-R)/OTV(2-E).

An insertion module is added to the launch stack as a second stage for launch vehicles 1, 2 and 3 in those cases where a performance gain is realized based upon the trajectory launch energy.

More extensive data are presented for orbiter missions than for flybys in order to examine trade-offs over various mission parameters. For each launch opportunity, facing pages of launch year trajectory data and initial injected mass for five candidate launch vehicles begin the section. A graph showing net orbited payload versus trip time for a selected set of trajectory types and launch vehicles follows. A sample plot is included as Figure 2-1. Launch

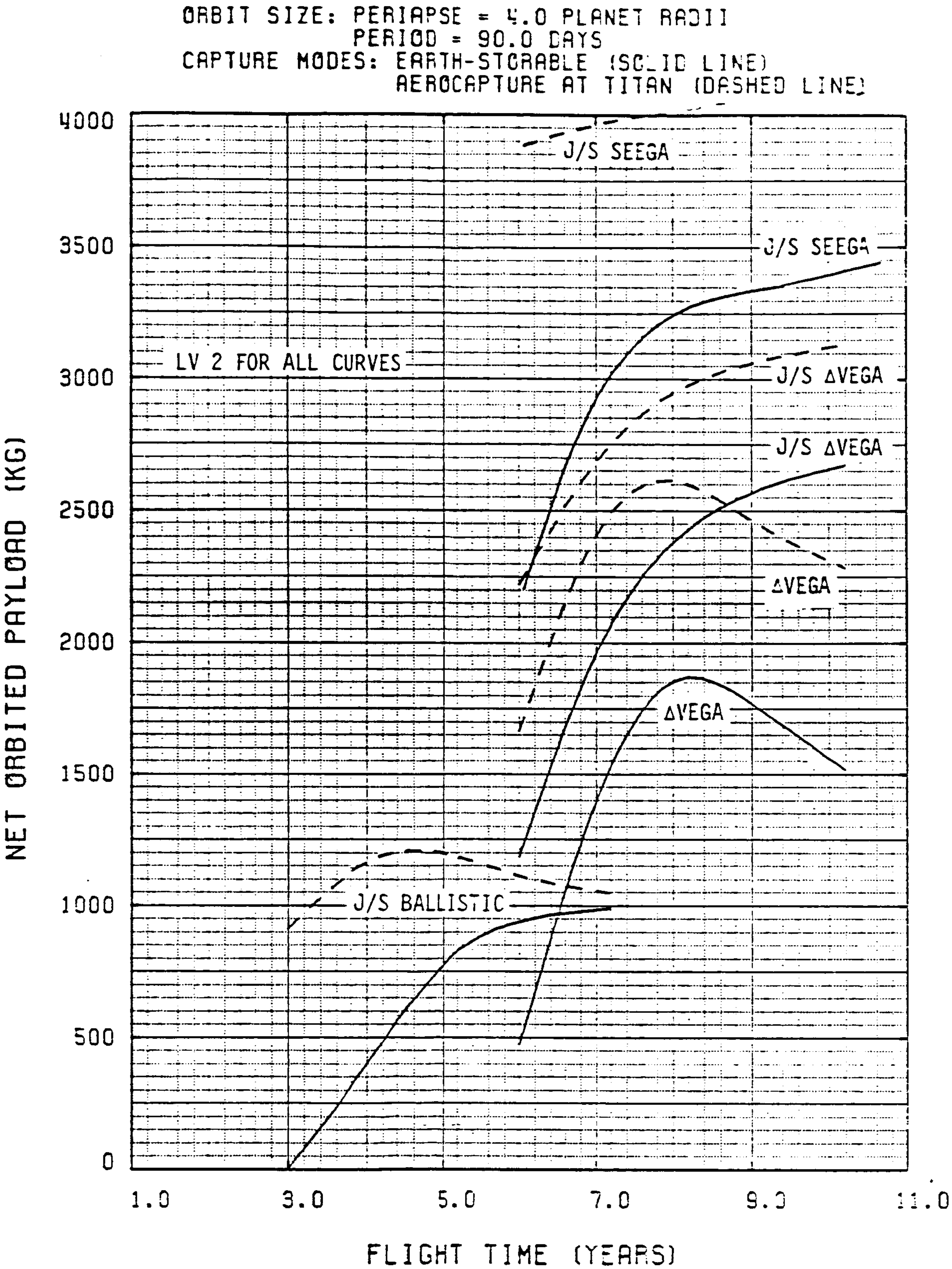


Figure 2-1. Sample Plot for PMPH Volume I

vehicles on this plot are identified by numbers as described above. A reference orbit size and retro stage are chosen for this purpose, which vary according to target. A set of several subsidiary tables which show payload variations for launch vehicles, retro stages and orbit sizes follows. For each relevant transfer mode, tabular data for each of two selected launch vehicles are presented. These data include aerocapture information for all targets but Jupiter and its satellites, and aerocapture at Titan or Triton where appropriate for orbit insertion about Saturn and Neptune, respectively. Sample tables are included as Table 2-5 for planet orbiter missions, and Table 2-6 for satellite orbiters.

The set of ballistic orbiter data for all opportunities is followed by a section of low-thrust data. SEEGA and NEP data presented are not launch opportunity dependent, with the exception of Jupiter swingby SEEGA cases. The SEEGA orbiter performance data for each target is preceded by a graphical summary of the SEEGA trajectory approach conditions, approach velocity and approach mass. The 1200 kg SEP stage is assumed to be jettisoned at thrust cut-off; therefore, the value of approach mass shown in the figures is net spacecraft mass plus the retropropulsion system. Orbit insertion is accomplished via chemical ΔV maneuvers as in the ballistic trajectory cases. This summary is followed by tabular information showing trade-offs in flight time and orbit size for the Shuttle/Centaur(G') launch vehicle only. This information includes Earth-storable retropropulsion and satellite aerocapture where applicable for the orbit insertion maneuver. The same information is also included for Jupiter swingby missions where the opportunity exists. The NEP orbiter performance data follow the SEEGA data.

NEP performance is presented in graphical format only as net orbited mass as a function of flight time. Due to the low-thrust nature of the trajectories, NEP data are not launch year dependent.

2.4 Inner Planets Mission Analysis

No activities were scheduled to be performed in this task area during the 1984-85 contract period.

Table 2-5

SATURN 1997 — ORBITER MASS PERFORMANCE

FLIGHT MODE: DIRECT BALLISTIC
LAUNCH VEHICLE: SHUTTLE/CENTAUR(G')/IM

*** NET USEFUL PAYLOAD (KG) ***

AEROCAPTURE

PERIOD (DAYS)	TRIP TIME (YEARS)	ORBIT PERIAPSE RADII (PLANET RADII) 1.1	2.0	3.0	4.0	6.0	8.0	20.2
90.0	2.50	287	272	260	250	233	220	164
90.0	3.00	411	389	372	357	333	314	234
90.0	3.50	470	446	425	409	381	359	268
90.0	4.00	486	460	439	422	394	371	277
90.0	4.50	479	454	433	416	388	366	273
90.0	5.00	460	436	416	400	373	351	262
120.0	2.50	288	275	265	256	242	231	183
120.0	3.00	411	394	379	366	346	330	261
120.0	3.50	471	450	433	419	396	378	299
120.0	4.00	486	465	448	433	409	390	309
120.0	4.50	479	459	441	427	404	384	304
120.0	5.00	461	441	424	410	388	369	293
150.0	2.50	288	277	268	261	248	238	196
150.0	3.00	412	396	383	373	355	341	280
150.0	3.50	471	454	439	426	406	390	320
150.0	4.00	486	468	453	441	420	403	331
150.0	4.50	480	462	447	434	414	397	326
150.0	5.00	461	444	429	417	398	382	314

AEROCAPTURE AT TITAN

PERIOD (DAYS)	TRIP TIME (YEARS)	ORBIT PERIAPSE RADII (PLANET RADII) 1.1	2.0	3.0	4.0	6.0	8.0	20.2
90.0	2.50	397	397	397	397	397	397	397
90.0	3.00	607	607	607	607	607	607	607
90.0	3.50	748	748	748	748	748	748	748
90.0	4.00	878	878	878	878	878	878	878
90.0	4.50	864	864	864	864	864	864	864
90.0	5.00	830	830	830	830	830	830	830
120.0	2.50	397	397	397	397	397	397	397
120.0	3.00	607	607	607	607	607	607	607
120.0	3.50	748	748	748	748	748	748	748
120.0	4.00	878	878	878	878	878	878	878
120.0	4.50	864	864	864	864	864	864	864
120.0	5.00	830	830	830	830	830	830	830
150.0	2.50	397	397	397	397	397	397	397
150.0	3.00	607	607	607	607	607	607	607
150.0	3.50	748	748	748	748	748	748	748
150.0	4.00	878	878	878	878	878	878	878
150.0	4.50	864	864	864	864	864	864	864
150.0	5.00	830	830	830	830	830	830	830

Table 2-5 (cont'd.)

SATURN 1997 —— ORBITER MASS PERFORMANCE

FLIGHT MODE: DIRECT BALLISTIC
LAUNCH VEHICLE: SHUTTLE/CENTAUR(G')/IM

*** NET USEFUL PAYLOAD (KG) ***

AEROCAPTURE

PERIOD (DAYS)	TRIP TIME (YEARS)	ORBIT PERIAPSE RADII (PLANET RADII) 1.1	2.0	3.0	4.0	6.0	8.0	20.2
90.0	2.50	287	272	260	250	233	220	164
90.0	3.00	411	389	372	357	333	314	234
90.0	3.50	470	446	425	409	381	359	268
90.0	4.00	486	460	439	422	394	371	277
90.0	4.50	479	454	433	416	388	366	273
90.0	5.00	460	436	416	400	373	351	262
120.0	2.50	288	275	265	256	242	231	183
120.0	3.00	411	394	379	366	346	330	261
120.0	3.50	471	450	433	419	396	378	299
120.0	4.00	486	465	448	433	409	390	309
120.0	4.50	479	459	441	427	404	384	304
120.0	5.00	461	441	424	410	388	369	293
150.0	2.50	288	277	268	261	248	238	196
150.0	3.00	412	396	383	373	355	341	280
150.0	3.50	471	454	439	426	406	390	320
150.0	4.00	486	468	453	441	420	403	331
150.0	4.50	480	462	447	434	414	397	326
150.0	5.00	461	444	429	417	398	382	314

AEROCAPTURE AT TITAN

PERIOD (DAYS)	TRIP TIME (YEARS)	ORBIT PERIAPSE RADII (PLANET RADII) 1.1	2.0	3.0	4.0	6.0	8.0	20.2
90.0	2.50	397	397	397	397	397	397	397
90.0	3.00	607	607	607	607	607	607	607
90.0	3.50	748	748	748	748	748	748	748
90.0	4.00	878	878	878	878	878	878	878
90.0	4.50	864	864	864	864	864	864	864
90.0	5.00	830	830	830	830	830	830	830
120.0	2.50	397	397	397	397	397	397	397
120.0	3.00	607	607	607	607	607	607	607
120.0	3.50	748	748	748	748	748	748	748
120.0	4.00	878	878	878	878	878	878	878
120.0	4.50	864	864	864	864	864	864	864
120.0	5.00	830	830	830	830	830	830	830
150.0	2.50	397	397	397	397	397	397	397
150.0	3.00	607	607	607	607	607	607	607
150.0	3.50	748	748	748	748	748	748	748
150.0	4.00	878	878	878	878	878	878	878
150.0	4.50	864	864	864	864	864	864	864
150.0	5.00	830	830	830	830	830	830	830

Table 2-6

TITAN 1993 —— ORBITER MASS PERFORMANCE

FLIGHT MODE: DIRECT BALLISTIC
LAUNCH VEHICLE: OOA/CENTAUR(G')/CENTAUR(G)

*** NET USEFUL PAYLOAD (KG) ***

3-IMPULSE CAPTURE WITH EARTH-STORABLE RETROPROPULSION

HELIOCENTRIC TRIP TIME (YEARS)	500 km CIRCULAR	1000 km CIRCULAR	500 km X 6 HR	1000 km X 6 HR
2.5	0	0	0	0
3.0	88	89	126	114
3.5	240	242	291	275
4.0	256	258	304	289
4.5	189	190	225	214
5.0	104	105	128	121

3-IMPULSE CAPTURE WITH SPACE-STORABLE RETROPROPULSION

HELIOCENTRIC TRIP TIME (YEARS)	500 km CIRCULAR	1000 km CIRCULAR	500 km X 6 HR	1000 km X 6 HR
2.5	0	0	0	0
3.0	117	118	158	145
3.5	276	278	329	312
4.0	266	268	314	299
4.5	168	170	204	193
5.0	59	60	82	75

AEROCAPTURE

HELIOCENTRIC TRIP TIME (YEARS)	500 km CIRCULAR	1000 km CIRCULAR	500 km X 6 HR	1000 km X 6 HR
2.5	684	664	692	673
3.0	1118	1084	1129	1098
3.5	1159	1125	1172	1139
4.0	955	927	966	939
4.5	663	643	670	652
5.0	381	370	385	375

2.5 Outer Planets Mission Analysis

Work performed in this task area consisted of a broad study of future missions to the outer planets and their satellites. The purpose of the study was to develop pre-Phase A mission concepts for candidate Augmentation missions to the Solar System Exploration Committee's recommended Core Program. A summary of the study results follows.

Introduction. The outer planets, from Jupiter with its diverse assemblage of 16 satellites to the virtual double planet of Pluto and Charon, exhibit a wide range of natural phenomena which differ greatly from anything found on Earth or among the inner planets. This variety has kept the science community active over the past several centuries attempting to determine the nature of these bodies, and comparing them to one another to better understand their differences and their similarities. The comparatively recent introduction of interplanetary spacecraft to this investigative process has done much to reveal the nature of these planets but has also generated an entirely new set of queries as each world is examined in greater detail.

Given the situation described above, the purpose of this study is to develop a "broad brush" picture of advanced mission concepts for outer planet exploration in the 1995-2015 time frame. This set of missions could satisfy most, if not all, of the Space Science Board recommendations for the outer planets not met by the proposed Solar System Exploration Committee (SSEC) Core Program. Each mission has a sufficiently detailed description of science objectives to allow candidate science instrument payloads, spacecraft functional requirements and mass breakdowns to be defined. This information allows performance and flight time trade studies to be conducted as well as key operational characteristics or design issues to be identified. A cost estimate for each mission is then developed, reflecting both the heritage from Core Program missions and the new technology required to meet the science objectives.

Science Objectives. Beginning with the assumption that the Voyager mission to Uranus and Neptune and the Galileo mission to Jupiter will be successful, COMPLEX established a strategy of scientific goals and objectives

to be met for any future missions to the outer planets. In light of the fact that Galileo will address the most important objectives at Jupiter (as established by COMPLEX in 1979), Saturn and its system have been given the highest priority for subsequent missions. The science objectives for Saturn as outlined by COMPLEX are:

1. Intensive study of the Saturn system as a whole;
2. First-order characterization of Titan's surface to guide the planning of future missions;
3. Determination of the composition and structure of Titan's atmosphere; and
4. Determination of the composition and structure of Saturn's atmosphere.

These objectives will be met by the proposed SSEC Core Program missions to Saturn. The first of these, the Saturn Orbiter/Titan Probe (Cassini), will focus on the first three objectives while the Saturn Flyby/Probe will address the fourth.

Further long-term objectives for the outer planets include:

1. Conduct a detailed long-term study of Saturn's rings, small satellites and magnetosphere;
2. Characterize the physical state of Titan's surface;
3. Conduct exploration and intensive study of the Uranus and Neptune systems with special attention to Neptune's moon Triton;
4. Conduct investigative studies on the planetology of the Galilean satellites and Titan;
5. Conduct intensive studies of Jupiter's inner system, including its satellites, inner magnetosphere, and time-dependent phenomena; and
6. Conduct measurements to the base of the cloud layer (or deeper) at the gas planets.

These objectives are the focus of the candidate mission concepts that are presented in this report. Any level of priority for these objectives will be dependent upon the results obtained from Voyager and Galileo.

Hardware Elements. Meeting these science objectives will, in most cases, require only the use of hardware concepts which have been derived or modified from existing elements built and tested for other missions. In this respect, the present study will follow the precedent set by the Mariner Mark II program in that hardware from diverse sources will be assembled to carry out the desired mission. For the mission concepts under consideration, there have been several previous spacecraft with similar flight profiles. For example, the Viking lander, the Voyager bus structure and antenna, and the Pioneer Venus probe pressure vessel, as well as the Galileo engineering subsystems and entry probe represent hardware elements which can be applied to other missions. Several missions may require hardware which has no analogue in previous spacecraft. In these cases, previous mission and vehicle design studies will be used to generate any required information.

In order to maintain a reasonable level of reliability for these missions, a flight time of less than 10 years has been imposed on all missions. To meet this requirement, two new concepts in the areas of upper stage propulsion and capture method must be invoked. Low-thrust propulsion and aerocapture are thus assumed to be available at the time of launch for any particular mission even though no definite plans to develop either technology exist at present. However, as will be seen in the following sections, both of these technologies will significantly improve the mass performance and flight times to the more distant planets.

The major hardware elements needed to carry out the proposed mission objectives have been listed in Table 2-7. This table also indicates the heritage assumed for each element and approximate mass values (rounded to the nearest five kilograms).

Table 2-7

MAJOR HARDWARE ELEMENTS

Hardware Element	Heritage	Estimated Mass (kg)
Support Bus (Ballistic)	Mariner Mark II/ Voyager/Galileo	745
Support Bus (Low-Thrust)	New	1360
Soft Lander	Viking	500
Hard Lander	New	30
Penetrator	Mars Penetrator Concept	55
20 bar Atmospheric Probe (without heat shield)	Galileo	90
100 bar Atmospheric Probe (without heat shield)	Pioneer Venus/Galileo	190
1000 bar Atmospheric Probe (without heat shield)	New	260
Balloon-Supported Probe	New	110
Airship-Supported Probe	New	335
Nuclear Electric Propulsion Stage (Dry)	New	5145
Solar Electric Propulsion Stage (Dry)	New	1200
Aerocapture Vehicle	New	Mission-Dependent

All mass values shown do not include science instruments or propulsion systems and thus represent only the support-type subsystems. In addition, minor variations may be made in each of these values based on the peculiarities of each mission.

The mixture of new and updated hardware technology will be accounted for in the cost estimate for each mission. The SAIC Cost Estimation Model for Advanced Planetary Programs used for these estimates accounts for varying degrees of heritage for each of the hardware elements.

Performance Trade Studies. Mission performance capability is a function of many parameters, including launch vehicle/upper stage, interplanetary

flight mode, trajectory type (which can be a function of launch year), the method of orbit capture, and the type of retropropulsion used for post-launch mission phases. The complete scope of options for each of these categories is summarized in Table 2-8.

The launch vehicle/upper stage combinations determine the total mass which can be injected into an interplanetary trajectory at the proper energy. The set used for this study includes the Centaur family of vehicles, plus a conceptual propulsion system derived from recent space-based Orbital Transfer Vehicle (OTV) studies at NASA/Marshall Space Flight Center. For this vehicle, designated OTV(4-R)/OTV(2-E), a reusable four-tank OTV (OTV(4-R)) propels the launch stack to a maximum 24-hour orbit, then returns to a Space Station-compatible orbit via aeromaneuvering. A two-tank expendable OTV (OTV(2-E)) then launches the spacecraft to escape from the perigee of the first-stage orbit.

Ballistic, solar electric propulsion (SEP) and nuclear electric propulsion (NEP) flight modes are all considered for the missions presented in this study. The delivery options are further increased by examining both direct and indirect trajectory types, as well as Jupiter gravity-assist swingbys. For missions to the outer planets, trajectories utilizing Jupiter gravity-assist swingbys can greatly reduce launch energy requirements and mission trip times. These trajectory types are especially useful for Uranus and Neptune missions due to the excessive launch energy and flight time requirements for direct ballistic trajectories.

The only trajectory types studied using SEP were the 2+ and 3+ SEEGA. The ballistic equivalent of this Earth gravity-assist trajectory type, the ΔVEGA, was also examined and both SEEGA and ΔVEGA were analyzed employing Jupiter gravity-assists. The advantage of the indirect trajectory types is the ability to capture the mission with a less capable launch vehicle due to the decreased launch energy requirements. However, these trajectory types will, in general, increase the total trip time by the length of time spent on the Earth-to-Earth leg.

Table 2-8

PERFORMANCE TRADE OPTIONS

- LAUNCH VEHICLE/UPPER STAGES
  - SHUTTLE/CENTAUR(G)
  - SHUTTLE/CENTAUR(G')
  - ON-ORBIT-ASSEMBLED OR FUELED (OOA) CENTAUR(G')
  - OOA CENTAUR(G')/CENTAUR(G)
  - OTV(4-R)/OTV(2-E)

- INTERPLANETARY FLIGHT MODES
  - BALLISTIC
  - NEP: 100 kW_e, I_{sp} = 5500 sec, μ = 0.776, M_{DRY} = 5145 kg
  - SEP: P_A = 32 kw (BOL), P_0 = 28 kw (BOL), I_{sp} = 3560 sec, η = 0.682, M_{DRY} = 1200 kg

- TRAJECTORY TYPES
  - DIRECT
  - INDIRECT: ΔVEGA, SEEGA

  JUPITER SWINGBYS IN COMBINATION WITH BOTH

- ORBIT CAPTURE MODES
  - EARTH-STORABLE RETRO: I_{sp} = 315 sec, f = 0.1332, M_I = 69.9 kg
  - SPACE-STORABLE RETRO: I_{sp} = 370 sec, f = 0.1350, M_I = 154.6 kg
  - AEROCAPTURE: BICONIC AEROSHELL, MODERATE L/D
  - SPIRAL CAPTURE WITH NEP FLIGHT MODE

- PERFORMANCE CALCULATIONS
  - L.V. ADAPTER = 5% M_{INJ}
  - MIDCOURSE NAVIGATION BUDGET: 0.050 km/sec PER PLANET-TO-PLANET LEG
  - ORBIT TRIM MANEUVERS = 0.100 km/sec
  - PROBE/PENETRATOR DEFLECTION MANEUVERS = 0.050 km/sec

The great potential of NEP application to outer planet missions lies in the fact that the nuclear reactor power source operates independently of its distance from the Sun. This characteristic of useful thrust acceleration at a large heliocentric distance allows the vehicle to slow down near the target planet and spiral into orbit capture. Likewise, the NEP stage can be used to spiral out from a nuclear-safe orbit about the Earth to escape conditions.

Two methods of effecting orbit capture were studied for the missions presented here: (1) impulsive orbit capture, employing chemical retropropulsion for performing the ΔV maneuver, and (2) aerocapture technology. The classical systems assumed are summarized in Table 2-8. Most recent studies of aerocapture have assumed use of a biconic vehicle with a moderate L/D. This vehicle makes a single deep pass through the atmosphere at the periapsis of its approach trajectory. Enough kinetic energy is removed by aerodynamic drag to capture the vehicle and place it in a transfer orbit to its final operational altitude.

Finally, the specifics of the assumed ΔV budgets, adapter masses, etc. used in making the calculations are summarized as the last item of Table 2-8.

Candidate Missions. Based on the science objectives outlined previously, 11 potential missions to the five outer planets were identified and examined. These include: four missions to Jupiter and its satellites; two missions to Titan and one mission each to Saturn, Uranus, Neptune and Pluto. The final mission in this set examines the consequences of modifying the Uranus Flyby/Probe spacecraft (a currently identified Core Program mission) into an orbiter/probe vehicle. Characteristics of these candidate missions are summarized in Table 2-9.

The four missions to Jupiter would: (1) investigate the inner magnetospheric region; (2) investigate atmospheric properties at various locations and depths; (3) establish a monitoring network on the Galilean satellites; and (4) conduct a detailed investigation of Europa. The inner magnetosphere mission would be carried out by a low-altitude (1000 km by 12 R_J) polar orbiter which will allow detailed cross-sectional measurements to be made of

Table 2-9

SUMMARY OF CANDIDATE MISSION CHARACTERISTICS

MISSION	FLIGHT MODE	TRAJECTORY TYPE	LAUNCH VEHICLE	CAPTURE MODE	FLT TIME (YRS)	INJ. MASS (kg)	TOTAL COST ($M)
1. JUPITER INNER MAGNETOSPHERE/POLAR ORBITER	BALLISTIC	DIRECT	CENTAUR(G')	E-S RETRO	2.2	2030	609
2. JUPITER DEEP PROBE/MULTIPROBE	BALLISTIC	DIRECT	OOA CENT(G')/ CENT(G)	E-S RETRO	1.9	4450	1401
3. GALILEAN SATELLITE PENETRATOR NETWORK	BALLISTIC	DIRECT	OOA CENT(G')/ CENT(G)	E-S RETRO	3.5	3866	1174
4. EUROPA ORBITER/LANDER	BALLISTIC	DIRECT	OTV/OTV	E-S RETRO	3.5	6120	1466
5. TITAN ORBITER/PENETRATOR NETWORK	BALLISTIC	DIRECT	OOA CENT(G')/ STAR 48	AEROCAPTURE	4.5	1960	1247
6A. TITAN ORBITER/BUOYANT STATION (ORBITER)	BALLISTIC	DIRECT	OOA CENT(G')/ STAR 48	AEROCAPTURE	4.5	1885 ORB	2481
6B. TITAN ORBITER/BUOYANT STATION (PROBE CARRIER)	BALLISTIC	DIRECT	OOA CENT(G')/ CENT(G)	FLYBY	4.2	2730	
7. SATURN RING ROVER	NEP	DIRECT	SHUTTLE	SPIRAL	10.4	16736	1245
8. URANUS ORBITER/PROBE	BALLISTIC	J/U	OOA CENT(G')/ STAR 48	E-S RETRO	11.0	1946	933
8A. URANUS ORBITER/PROBE	BALLISTIC	J/U	CENTAUR(G')	AEROCAPTURE	9.0	5163	985
9. URANUS ORBITER/MULTIPROBE	BALLISTIC	J/U	OTV/OTV	AEROCAPTURE	6.0	4955	1403
10. NEPTUNE ORBITER/DUAL PROBE	BALLISTIC	J/N	OTV/OTV	AEROCAPTURE	7.0	3947	1562
10A. NEPTUNE ORBITER/DUAL PROBE	NEP	DIRECT	OTV/OTV	SPIRAL	8.3	17649	1799
11. PLUTO ORBITER/LANDER AND CHARON LANDER	NEP	DIRECT	OTV/OTV	SPIRAL	7.7	14648	1489

the inner magnetosphere and the charged particle radiation belt. The multiprobe mission would deliver four atmospheric probes to various latitudes, longitudes, and depths within Jupiter. Three of these probes would be identical to the Galileo probe with at least one of the three targeted for the Great Red Spot. The remaining probe would be designed to survive to a 1000 bar pressure level and would be targeted at the equator. The third candidate mission would deliver penetrator-type monitoring stations to the three outer Galilean satellites as part of a flyby tour to survey these bodies. The last candidate mission for Jupiter would deliver a Viking-class lander to the surface of Europa while an orbiting vehicle conducts a planet-wide survey. This mission could also be carried out at Ganymede or Callisto, but Europa was chosen here because it would be the most challenging mission to complete based on the performance requirements to reach this satellite.

Of the three missions identified for the Saturn system, two would be directed at Titan and one at Saturn itself. The two Titan missions consider alternate means of conducting detailed investigations of the entire satellite. Each mission would have an orbiter to carry out a planet-wide survey. Both missions would also use entry probes which would deliver surface penetrators and/or buoyant stations with varying levels of sophistication. The buoyant station vehicles would range from simple free-drift balloons to controllable airships. The major difference between these two missions would be in the number and type of entry probes used. The single mission targeted for Saturn itself would use a nuclear electric low-thrust stage to investigate the ring system by essentially hovering above the ring in a non-Keplerian orbit.

Two missions to Uranus were examined as part of this study. The first of these looked at the currently identified Flyby/Probe mission and estimated the cost to upgrade this into an orbiter/probe mission. While the basic science objectives and instrumentation of the mission would not be changed, this does represent a moderate augmentation due to the increased costs for extended mission operations and the additional propulsion capability or aerocapture vehicle needed for orbit capture. The single new mission to Uranus would deliver three atmospheric probes, designed to survive to 100 bars pressure, into the planet. An orbiter would then continue with a detailed investigation of the planet, its ring system and satellite system.

Neptune would be targeted for a single mission. As part of the scientific investigation to be carried out, a single atmospheric probe would be deployed separately into both Neptune and Triton. Again, an orbiting vehicle (which delivered the probes) would carry out an overall survey of the planet and its satellite system. Two delivery system options were considered for this mission: a NEP option and an aerocapture option. These two options were both carried throughout the study since Neptune is the approximate point at which it becomes more economical to use NEP systems rather than aerocapture for an orbital mission of this type.

A basic assumption made for the single Pluto mission was that it would be the first close-up investigation of this planet and its satellite Charon. A low-thrust NEP stage was chosen since this is the only reasonable means of delivering a spacecraft to Pluto in a non-excessive period of time. This vehicle would deliver a small hard landing probe to the surface of each body and then continue with a detailed survey of this planetary system.

The major characteristics for each of these missions, including trajectory data, injected mass requirements and estimated cost, have been summarized in Table 2-9.

Summary. The wide range of spacecraft and missions just discussed indicates the breadth of knowledge still to be obtained from exploration of the outer planets. The Committee on Planetary and Lunar Exploration (COMPLEX) of the Space Science Board has established a number of scientific objectives to help fill some of the gaps in the present understanding of these planets. The Saturn Orbiter/Titan Probe mission (Cassini) and the Saturn Flyby/Saturn Probe mission, which have both been included in the SSEC Core Program, will meet several of these objectives. The purpose of this study has been to examine possible mission concepts to be carried out in the 1995-2015 time period which will fulfill the remainder of the objectives. Eleven candidate missions were identified and examined. It was found that existing hardware elements and concepts could be used to carry out most of these missions. There were several exceptions which occurred due to the nature of the mission involved. Some of these required unique solutions such as the airship concept

used at Titan. Others required hardware, such as NEP or aerocapture, to fulfill mission needs which would have a wider range of application in the future. The cost for these new missions was found to range from $609M to $2481M in FY 1986 dollars. All of the mission concepts tend to be ambitious in scope and, in most cases, could be split into separate missions to reduce individual mission costs. There were no identified technological impediments to meeting any of the desired science objectives.

2.6 Small Bodies Mission Analysis

Work performed in the area of comet and asteroid mission analysis consisted of two major subtasks. The first of these was essentially a continuation of the previous year's Comet Nucleus Sample Return study. The second subtask focused on comet coma sample return opportunities with emphasis on ballistic "free return" trajectory performance.

2.6.1 Comet Nucleus Sample Return Study

In preparing for a planned study to be conducted jointly with JPL and JSC, our previous year's Comet Nucleus Sample Return (CNSR) study efforts were reviewed in order to identify key mission design issues that were either left unaddressed in that study or were perceived to require further investigation. These issues, listed in Table 2-10, were to form the basis of the present year's study. In particular, this preliminary effort accomplished the following:

1. It identified the need to have a better working definition of a comet nucleus to serve as a basis for design decisions relating to landing, anchoring and sampling.

2. It suggested that greater attention be paid to an aphelion encounter option, in view of the previously identified risks and constraints imposed by perihelion missions and by a newly devised SEP/chemical hybrid propulsion option that would bring a single Shuttle launch performance capability to aphelion missions.

3. It indicated a continued need for performance analyses to support new mission options, particularly to cover the expanded emphasis on aphelion missions called for above, and

Table 2-10

MISSION DESIGN ISSUES

- COMET NUCLEUS MODEL
- PERIHELION vs APHELION
- PROPULSION/FLIGHT MODE/PERFORMANCE
- SAMPLING TECHNIQUE
- ANCHORING
- THERMAL/ENVIRONMENTAL CONTROL
- SAMPLE RECOVERY & CONTAINMENT
- ADAPTABILITY

to examine in detail the performance implications of the hybrid propulsion mode and the use of aerocapture for Earth return.

4. It stressed the importance of developing sampling and anchoring concepts that are sufficiently adaptable to operate successfully over a wide spectrum of possible comet surface and subsurface parameters.

5. It reaffirmed the need for a more detailed examination of the thermal/environmental requirements and techniques for sample protection, especially when faced by the heating and G-loading conditions imposed by aerocapture, and the thermal IR radiation in low-Earth orbit.

6. It called for an investigation of methods for sample recovery and containment, a subject not addressed in the previous study.

SAIC Preliminary Analysis. Brief analyses relating to the performance, sampling and anchoring issues were conducted as part of the above effort. The performance analyses examined a broad sample of ballistic perihelion and aphelion opportunities for the comets C-G, HMP, Kopff, Tempel 2 and Wild 2. Looking at direct as well as ΔVEGA modes, and both aerocapture and solid rocket Earth orbit injection techniques, these opportunities are identified in Table 2-11, and displayed in the mission capture diagram of Figure 2-2. The results show that over this wide range of cases, only aphelion missions using ΔVEGA trajectories and employing aerocapture returns could be accomplished with a single Shuttle launch. The predominant number of ballistic opportunities were found to require multiple Shuttle launches for either on-orbit fueling or assembly of stacked Centaur stages.

The brief examination of sampling technology focused on drill coring requirements and capabilities, with special attention given to their adaptability to potential comet surfaces ranging from soft snow to hard crystalline ice. The analysis was based on coring auger performance data made available by the Cold Regions Research and Engineering Laboratory (CRREL) of the U.S. Army Corps of Engineers. Values of required torque and thrust were computed parametrically for varying penetration rates over the indicated range of surface strengths. The results, plotted in Figure 2-3, show that the dominant requirement for sampling hard surfaces, such as ice, is the downward force

Table 2-11

BALLISTIC CNSR MISSION CAPTURE

COMET	LAUNCH DATE	ROUND TRIP TIME (yrs)	FLIGHT MODE
• SHUTTLE/CENTAUR G'			
C-G	OCT 2000	9.2	ΔV-A/D-AC
WILD 2	APR 2001	7.9	ΔV-A/D-AC
KOPFF	JUN 2001	8.1	ΔV-A/D-AC
• OOA CENTAUR G'			
TEMPEL 2	JUN 1998	11.1	ΔV-P/D-AC
H-M-P	OCT 1998	8.2	ΔV-A/D-AC
WILD 2	APR 2001	10.2	ΔV-A/ΔV-CH
WILD 2*	MAR 2003	6.0	D-A/D-AC
• OOA CENTAUR G'/CENTAUR G (NOT REQUIRING AEROCAPTURE RETURN)			
WILD 2	MAR 1998	12.2	D-P/ΔV-CH
TEMPEL 2	JUN 1998	11.1	ΔV-P/D-CH
H-M-P	OCT 1998	8.2	ΔV-A/D-CH
C-G	OCT 2000	9.2	ΔV-A/D-CH
KOPFF	JUN 2001	8.1	ΔV-A/D-CH

* W/STAR 48 KICK STAGE

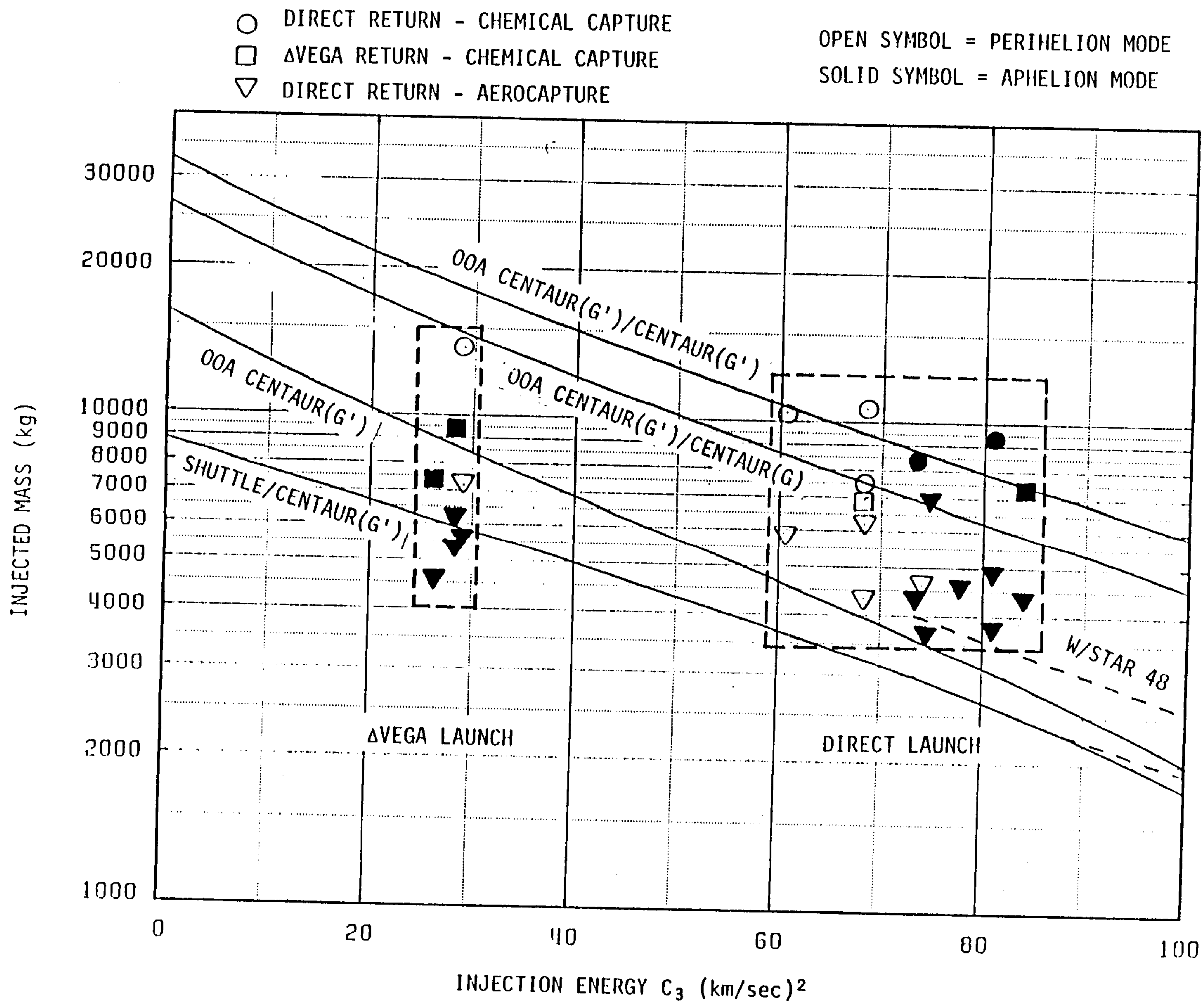
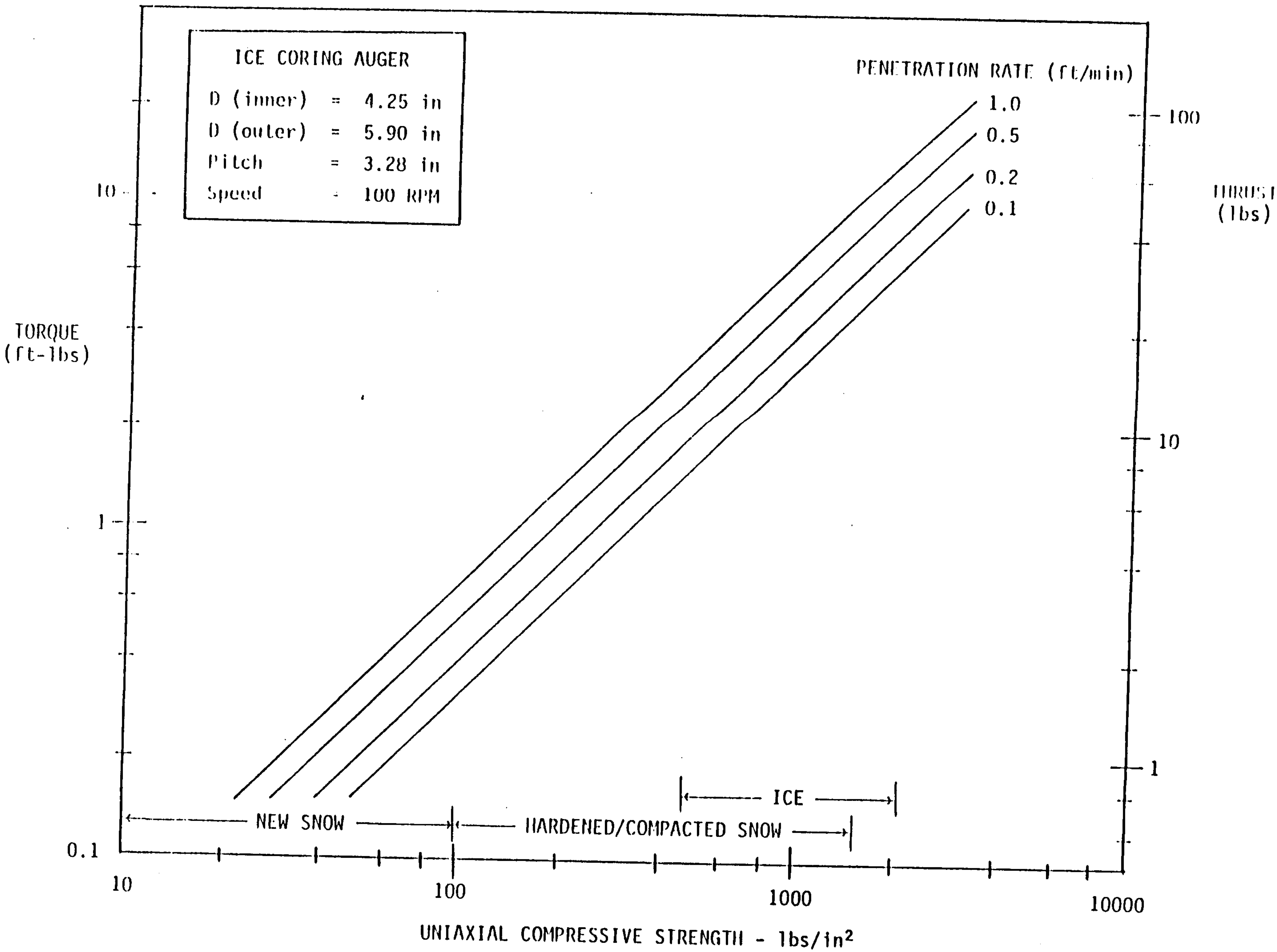


Figure 2-2. BALLISTIC CNSR MISSION CAPTURE (C-G, H-M-P, KOPFF, TEMPEL 2, WILD 2)

Figure 2-3.
CORING REQUIREMENTS FOR SNOW AND ICE



that must be applied by either thrusters on the sampling device/lander or reaction resistance supplied by an anchoring system. The thrust magnitudes needed for drilling (or implanting anchors) in icy surfaces are large enough to make cold gas (N_2) thrusters impractical for this application and point instead to monopropellants such as hydrazine. Assuming the surface is ice with a typical compressive strength of 1000 lbs/in^2, the needed thrust magnitudes are shown to range from approximately 15 to 30 lbs for penetration rates of 0.1 ft/min to 1 ft/min. Based on these values, a hydrazine thruster system with an I_{SP} of 235 sec would, for example, consume about 40 lbs of propellant drilling one meter into the surface at a rate of 0.5 ft/min. A cold gas system with an I_{SP} of 80 sec would, under the same conditions, expend approximately 118 lbs if, in fact, it could even deliver the required 24 lbs of thrust.

The thrust requirements described above could be alleviated considerably if an effective anchoring system could be developed that relieved the thrusters from supplying the large downward force during the drilling process, and yet did not require equivalent thruster performance to implant the anchors. As part of the preliminary study, several novel anchoring techniques were conceived that appeared to satisfy this requirement. Three such concepts are illustrated in Figures 2-4, 2-5, and 2-6. In the first concept, the lander uses the rotational energy of the core drill to embed spade-like landing legs into the surface where they can then serve as anchors for the subsequent drilling/sampling operation. The second concept uses a multitude of hooked-end, spider-like arms to grasp the surface and retain that contact in a manner similar to "velcro". In the third concept, the lander is configured as the aft portion of a penetrator which anchors itself on impact. A contained coring drill would then be pushed through the nose of the penetrator to collect the sample and return it to the lander.

SAIC Joint Study Effort. In addition to participating in the development of a reference mission for the joint CNSR study, SAIC was given primary responsibility for three major study elements: mission performance analyses, comet nucleus modeling, and cost estimation.

Figure 2-4.

LANDER ANCHORING CONCEPT - ROTATING SPADE LEGS

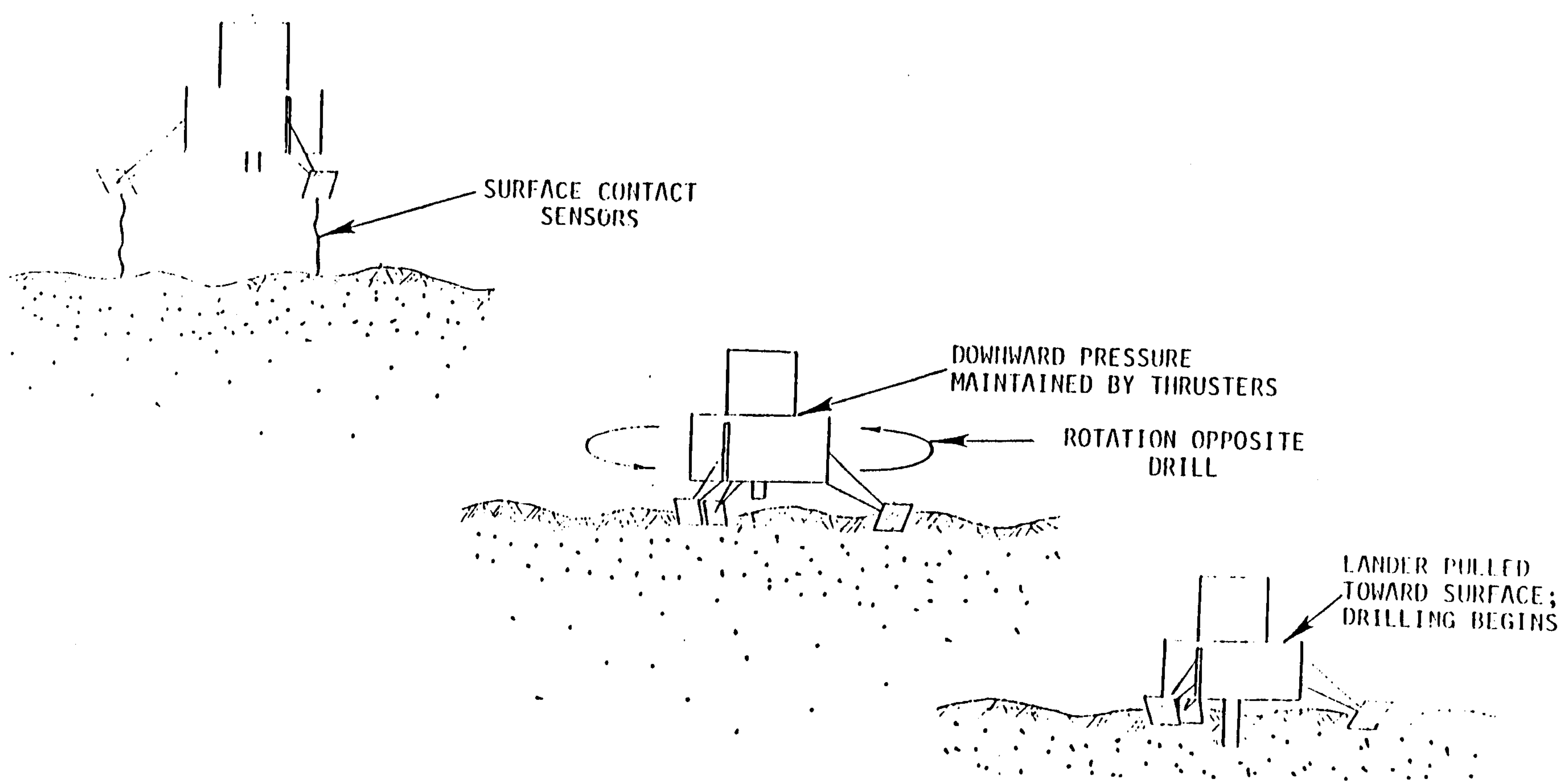


Figure 2-5.

LANDER ANCHORING CONCEPT - INDEPENDENT SURFACE GRAPPLING ARMS

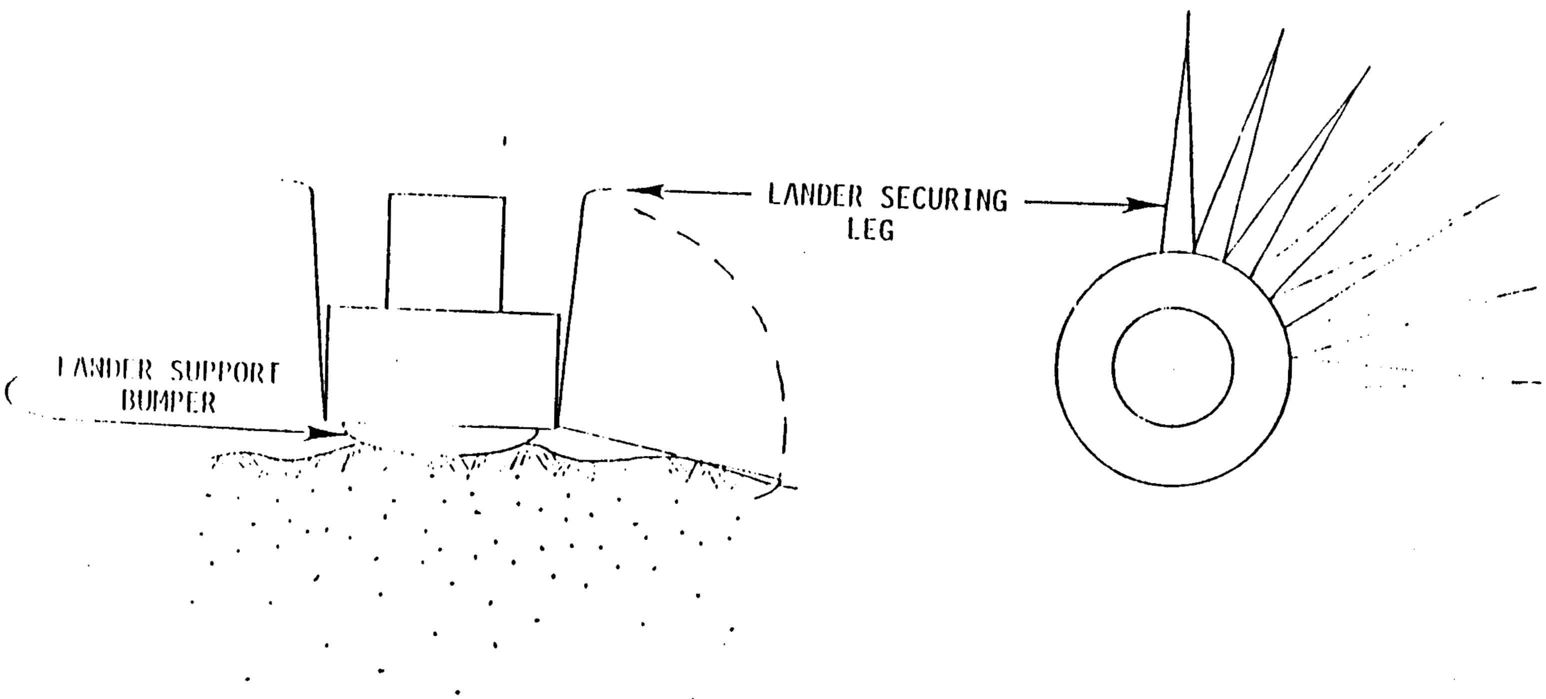
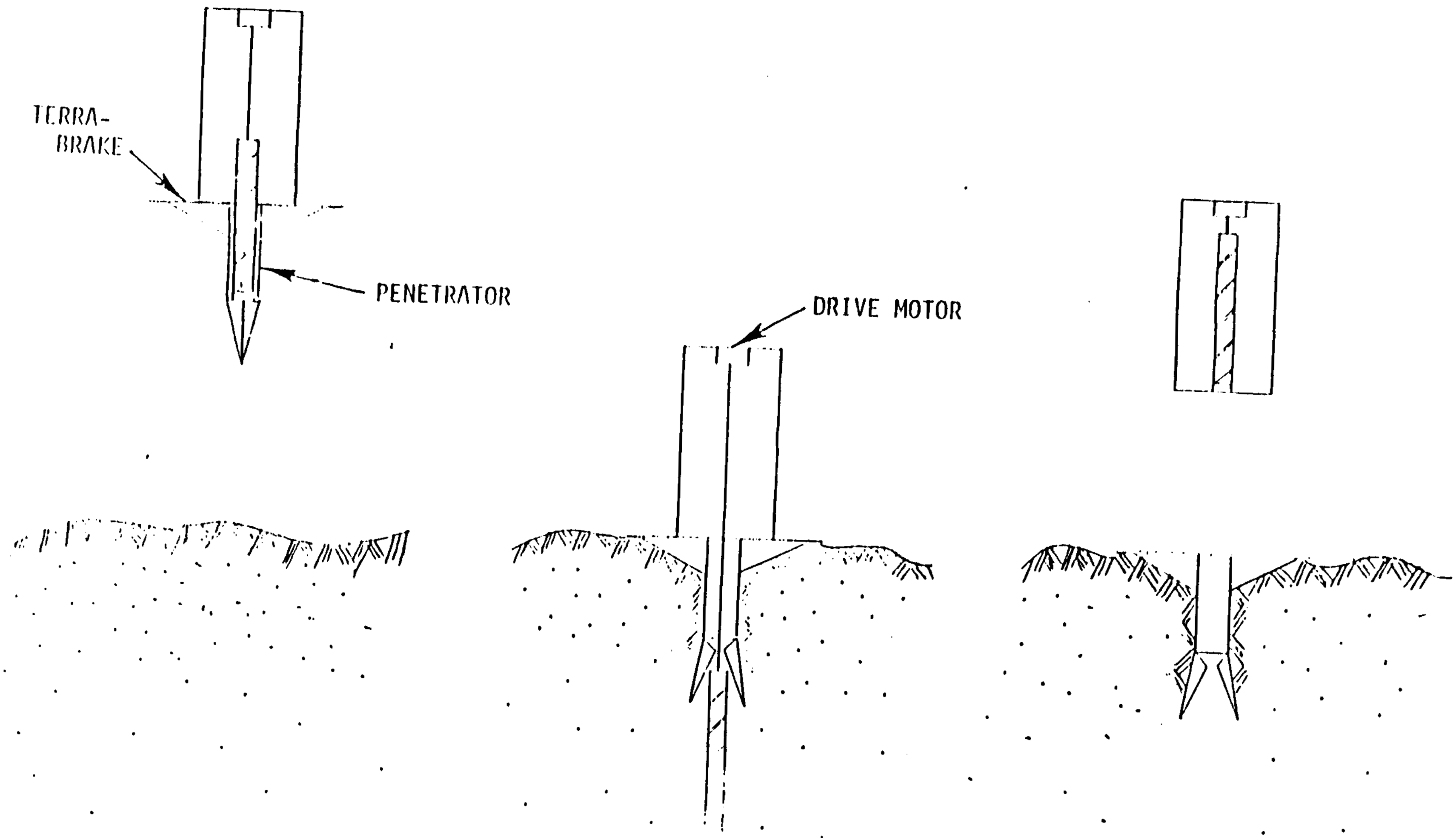


Figure 2-6.
PENETRATOR/DRILL SAMPLE COLLECTION CONCEPT



Mission Performance. Reference mission guidelines, stated at the onset of the study, were that the target would be the same comet visited during the CRAF mission in order to use the knowledge gained from that rendezvous to develop an appropriate lander design and sampling technique, and that sampling would take place at aphelion to minimize the potential hazards of comet activity. The mission performance analyses were therefore focused on Comets Kopff and Wild 2, each of which was once the prime target for CRAF. (Kopff was the CRAF target at the start of the study and was later replaced by Wild 2.) Also, in accordance with the stated guidelines, trajectories were selected to achieve rendezvous near the target comet's aphelion (at positions ensuring good Earth communications). Two successive aphelion passage opportunities were considered for each comet in the time period of interest. For Kopff, the opportunities were based on aphelion passages occurring in 1999 and 2006, and for Wild 2 the opportunities were based on aphelion passages in the years 2000 and 2006.

The propulsion modes considered in the analysis were the following: all-ballistic, SEP/chemical hybrid, and NEP. These were examined in combination with various Earth return orbit capture options, including solid rocket retropropulsion and aerocapture for the ballistic return modes, and low-thrust spiral capture for NEP. The NEP analyses also looked at a spiral escape option for the outbound leg. A SEP system power requirement, based on the use of a flat array, was computed individually for each mission option in which SEP was employed. The NEP in these analyses was presumed to be a 100 kw system similar to SP-100.

A summary of the performance analyses is given in Table 2-12. These results were derived using JPL-supplied vehicle mass estimates for the reference mission. The chemical flight modes shown in the table assume Earth-storable retropropulsion for spacecraft maneuvers and aerocapture for Earth return. Also examined, but not reported here, were options employing space storable retros and/or solid rocket orbit injection at Earth. All the NEP results assume spiral capture at Earth.

Table 2-12

CNSR PROPULSION/FLIGHT MODE PERFORMANCE

TARGET	LAUNCH YR	FLT MODE	RT TIME (YRS)	C3 (km^2/sec^2)	INJ MASS	LAUNCH VEHICLE
WILD 2	1996	SEP (23 KW)/CHEM	7.2	1	6850	SHUTTLE/CENTAUR G'
	1997	SEP (27 KW)/CHEM	6.2	1	8400	SHUTTLE/CENTAUR G'
	2003	SEP (18 KW)/CHEM	7.2	1	5550	SHUTTLE/CENTAUR G'
	1997	CHEM DIRECT	6.0	74.9	5150	OOA CENTAUR G'/CENTAUR G
	1998	CHEM DIRECT	5.0	79.1	7000	OOA OTV(4-R)/OTV(2-E)
	2002	CHEM ΔVEGA	8.2	27.5	6000	OOA CENTAUR G'
	2004	CHEM DIRECT	6.1	76.3	5050	OOA CENTAUR G'/CENTAUR G
	2002	NEP (100 KW)/SPIR ESC	8.3	--	12200	SHUTTLE
	2004	NEP (100 KW)	7.1	16	9750	OOA CENTAUR G'
	2005	NEP (100 KW)	6.0	16	11300	OOA OTV(4-R)/TOS
KOPFF	1995	SEP (17 KW)/CHEM	7.2	1	5000	SHUTTLE/CENTAUR G'
	1996	SEP (25 KW)/CHEM	6.2	1	8200	SHUTTLE/CENTAUR G'
	2002	SEP (18 KW)/CHEM	7.2	1	5400	SHUTTLE/CENTAUR G'
	1996	CHEM DIRECT	6.0	80	4100	OOA CENTAUR G'/CENTAUR G
	1997	CHEM DIRECT	5.0	80	5600	OOA CENTAUR G'/CENTAUR G
	2001	CHEM ΔVEGA	8.1	28.4	5200	SHUTTLE/CENTAUR G'
	2003	CHEM DIRECT	6.0	80.9	4150	OOA CENTAUR G'/CENTAUR G
	2002	NEP (100 KW)/SPIR ESC	8.2	--	13000	SHUTTLE
	2003	NEP (100 KW)	7.1	16	10100	OOA CENTAUR G'
	2003/4	NEP (100 KW)	6.0	16	11900	OOA OTV(4-R)/TOS

CHEMICAL FLIGHT MODES ASSUME EARTH STORABLE RETROPROPULSION AND AEROCAPTURE AT EARTH RETURN

NEP FLIGHT MODES ASSUME SPIRAL CAPTURE AT EARTH RETURN

SAMPLE: 10 KG; CONTAINER: 23 KG; ERV: 149 KG; AC MODULE: 197 KG; DROP MASS: 533 KG (300 KG FOR NEP)

The results indicate that the hybrid SEP/chemical propulsion mode allows the CNSR mission to be accomplished with a single Shuttle launch. The launch would require a Centaur(G') upper stage, and for a round trip flight time of approximately seven years, the SEP power requirement could range from 17 to 23 kw (BOL) depending on the opportunity. Reduction of the trip time by one year (perhaps to permit better use of information obtained from CRAF) would require an increase in SEP power to a range of 25 to 27 kw.

All other flight modes, with the exception of NEP with spiral escape, are found to require multiple Shuttle launches, either for on-orbit assembly of stages or on-orbit fueling. The NEP mission using spiral escape can be launched directly from the Shuttle, but has the disadvantage of requiring the longest flight time of any of the listed options.

Comet Nucleus Modeling. The approach taken to developing a scientific/engineering model of a comet nucleus was to conduct a workshop, gathering together prominent scientists with established credentials in the area of comet modeling. The purpose of the workshop was to define the characteristics of cometary nuclei in sufficient detail to permit preliminary design of the CNSR mission and systems to proceed with increased confidence.

The workshop was conducted in two phases. A preliminary meeting was held in Tucson, Arizona on January 12, 1985 in order to introduce the comet nucleus modeling task to potential participants, and to obtain their inputs regarding important issues and parameters to be considered during the workshop proper. The attendees of that meeting are listed in Table 2-13. Together, they produced a preliminary table of relevant comet parameters to be used as a "strawman" model for the workshop deliberations.

The workshop itself was held in Tucson on March 9, 1985. It was chaired by Humberto Campins of SAIC/PSI and was attended by the participating scientists and observers listed in Table 2-14. Other scientists who contributed material to the workshop but who were unable to attend included: B. Dunn (NASA/GSFC), M. Hanner (JPL), Z. Sekanina (JPL), R. Smoluchowski (U. of Texas), and F. Whipple (SAO). Collectively, through their backgrounds and

Table 2-13

COMET NUCLEUS MODELING MINI-MEETING

OBJECTIVE:	TO INFORMALLY BRING TOGETHER COMET SCIENTISTS PRESENT AT THE GALAXY AND SOLAR SYSTEM MEETING (JANUARY 10-12) IN TUCSON FOR THE PURPOSE OF INTRODUCING THE NUCLEUS MODELING TASK/WORKSHOP AND TO OBTAIN PRELIMINARY INPUTS.	
MEETING DATE:	JANUARY 12, 1985	
ATTENDANCE:	H. CAMPINS	SAIC/PSI
	W. HARTMANN	SAIC/PSI
	M. A'HEARN	U. MARYLAND
	A. DELSEMME	U. TOLEDO
	S. LARSON	U. ARIZONA
	D. MORRISON	U. HAWAII
	R. SMOLUCHOWSKI	U. TEXAS
	P. WEISSMAN	JPL

Table 2-14

COMET NUCLEUS MODELING WORKSHOP

OBJECTIVE: TO PRODUCE A SCIENTIFIC/ENGINEERING MODEL OF COMET NUCLEUS IN SUFFICIENT DETAIL TO PERMIT PRELIMINARY DESIGN OF CNSR MISSION AND SYSTEMS TO PROCEED WITH INCREASED CONFIDENCE

DATE: MARCH 9

LOCATION: PLAZA INTERNATIONAL HOTEL - TUCSON, ARIZONA

ATTENDEES:

PARTICIPANTS	
M. A'HEARN	U. MARYLAND
A. DELSEMME	U. TOLEDO
F. FANALE	U. HAWAII
H. HOUPIS	UCSD
S. LARSON	U. ARIZONA
D. MENDIS	UCSD
S. SQYRES	NASA/ARC
P. WEISSMAN	JPL
L. WILKENING	U. ARIZONA

OBSERVERS	
D. BLANCHARD	NASA/JSC
H. FEINGOLD	SAIC
J. FRENCH	JPL
R. POWELL	NASA/HQ

CONTRIBUTORS	
B. DONN	NASA/GSFC
R. SMOLUCHOWSKI	U. TEXAS

CHAIRMAN H. CAMPINS SAIC/PSI

recent research endeavors, the participants brought to the workshop the most current body of observational data, theory and modeling approaches relating to comet nucleus composition and structure possible at the time.

The models discussed during the workshop differ in their degree of sophistication and/or in the nuclear parameters they deal with (chemical composition, surface temperature, etc.); however, they are all based on, or are equivalent to, Whipple's icy conglomerate model. They assume roughly the same initial chemical composition which is based on the expected "cosmic" composition of cometesimals. They are also in agreement over the physical processes which can modify the original nature of cometary material, namely, cosmic ray bombardment of the surface layers and solar heating of the surface layers and interior, which cause sublimation, phase changes, chemical reactions, etc. in the ices.

There is mild disagreement between some of the models on the detailed chemical composition, the current level of differentiation and the internal structure of the nucleus. This disagreement is not surprising considering how few constraints there are on these problems.

There is, however, a consistent picture of the nucleus surface which emerges from these models. The parameter set which characteristizes this "consensus" model is given in Table 2-15. The "consensus" picture can be described as follows: The nucleus is likely to be non-spherical with axial ratios of as much as two to one. The surface topography will be irregular on a scale of a few meters. A fraction of the surface will be covered by a dust mantle which could reach a depth of one meter but is likely to be closer to 0.1 meter. The fraction of mantle coverage varies from almost zero in some comets to 90% or more in the case of Comet Encke. This value can be estimated from observations once the target comet has been chosen. The mantle can be a fragile but cohesive structure (friable sponge) or loose dust. However, even loose dust seems to show some degree of cohesiveness under the expected conditions of the nucleus surface. The areas of exposed ice need not have much higher albedo than the dust mantle. This is because an intimate mixture of ice and fine dust can have an albedo as low as that of pure dust with as

Table 2-15

COMET NUCLEUS MODEL PARAMETER SET

	MIN	EXPECTED	MAX	COMMENTS
ALBEDO (GEOMETRIC)	0.01	0.05	0.5	
DEPTH OF LAG DEPOSIT	0.01mm	≈10 cm	100 cm	
SURFACE TEMPERATURE	100 K•	130 K	170 K (subsolar pt)	•Could be less at poles
TEMPERATURE AT SAMPLING DEPTH		130 K		Asymptotic value
DIAMETER		5 km		Wild 2 geometric mean, axial ratio 2:1
ROTATION PERIOD	3 h	10-15 h*		*Wild 2
GAS PRODUCTION RATE (Molecules/Sec)	10^{26}		10^{27} (<2AU)	Wild 2 - Kopff New values available whe photometry reduced
DUST/GAS RATIO	0.4	0.6-0.8	1.0	
SURFACE DENSITY (gr/cm^3)	0.005*	0.05	1.0	*Top 1 cm lag deposit
DENSITY AT DEPTH (gr/cm^3)	0.1	1.0	1.5	
THERMAL CONDUCTIVITY (mw/cm K)	0.02	1 - 2	100	
SPECIFIC HEAT (cal/gr K)	0.3	0.5-0.8	1.0	
COHESIVENESS [Tensile Strength (dy/cm^2)]	10^2	10^4-10^5	10^8*	*Solid crystalline ice
COMPRESSIVE STRENGTH (dy/cm^2)	10^3	10^5	10^9*	•Solid crystalline ice
HARDNESS (Penetrability)	2	10	≥50	The range given is from block ice to fluffy snow in a relative scale
GRAIN/PARTICLE SIZE (Number Dist.)	<0.1 μm	0.1 μm-10 cm	>10 cm	
POROSITY (Pore Volume/Total Volume)	0.1	0.3	0.8	
EXPECTED GRAVITY		≈10^{-4}g		

little as one to 10% (by mass) of dust in the icy matrix. When the comet is close to the Sun, these exposed areas will have higher outgassing but not necessarily higher albedo. When there is no outgassing, the mantled and exposed areas may or may not look similar. Directly below the dust mantle, unconsolidated ice grains and larger dust particles would be found. Next would be a matrix of clathrate ices and dust, and below that, the core of clathrate hydrates, ices of the more volatile species and dust.

Many of the parameters given in Table 2-15 have large uncertainties. In some cases (e.g., rotation period, etc.), Earth-based observations can reduce the uncertainties. However, a few of these parameters (penetrability, etc.) will remain uncertain until *in situ* measurements are possible.

Cost Estimates. Class C cost estimates for CNSR, shown in Table 2-16, were prepared using the SAIC Planetary Program Cost Model. Costs were estimated for two different implementation modes: (1) all flight hardware development in-house at JPL, and (2) all flight hardware procured via system contracts. Costs were estimated for each mode using the estimated inheritance factors supplied to SAIC by JPL. This heritage is predicated on approval of the CRAF mission and follow-on Mariner Mark II missions. Costs were also estimated assuming no inheritance for both modes in order to obtain reasonable upper bound estimates for this mission configuration/concept.

The cost estimates are for the development project only and do not include costs for: flight operations beyond launch + 30 days; data analysis; sample recovery/quarantine; archiving; STS operations; injection stages; and on-orbit assembly or fueling operations.

2.6.2 Comet Coma Sample Return Opportunities

Introduction. The coma sample return mission, recommended by the SSEC as part of the Core Program, would provide for the return to Earth of a sample of the volatile and nonvolatile constituents of the coma of a comet. The sample would be collected during a flythrough of the inner coma by a spacecraft which is on a free-return trajectory to Earth. Volatile constituents could be

Table 2-16

CNSR DEVELOPMENT COST SUMMARY - FY 1985 $M

	CRAF/MMII HERITAGE (1)		NO HERITAGE (UPPER BOUND)	
	IN-HOUSE MODE	SYSTEMS CONTRACT	IN-HOUSE MODE	SYSTEMS CONTRACT
PROJECT MANAGEMENT	25.8	26.8	37.0	38.5
SCIENCE DEVELOPMENT	29.0	29.0	52.5	52.5
HARDWARE DEVELOPMENT	309.7	309.7	435.0	435.0
CONTRACT G/A + FEE (20%)	---	73.0	---	105.2
TOTAL FLIGHT HARDWARE	364.7	438.5	524.5	631.2
CONTRACT MANAGEMENT (7.7%)	---	33.8	---	48.6
MISSION DESIGN	35.0	35.0	40.0	40.0
MODULE INTEGRATION	14.0	14.0	22.2	22.2
LAUNCH + 30 DAYS OPS	24.9	24.9	36.0	36.0
RTGs	20.0	20.0	25.0	25.0
PROGRAM MANAGEMENT	13.8	17.0	19.4	24.1
CONTINGENCY (30%)	141.6	174.9	200.1	248.1
TOTAL (2)	613.8	758.0	867.3	1075.2

(1) ASSUMES APPROVAL OF CRAF MISSION AND FOLLOW-ON MARINER MARK II MISSIONS

(2) TOTAL DOES NOT INCLUDE: FLIGHT OPERATIONS BEYOND L + 30 DAYS, DATA ANALYSIS, STS OPERATIONS, INJECTION STAGES, ON-ORBIT ASSEMBLY/FUELING OR EARTH RECOVERY/QUARANTINE/ARCHIVING

collected by chemical absorption onto appropriate collection surfaces. The nonvolatile dust particles could possibly be collected intact by decelerating them in an underdense medium such as styrofoam, or in atomized form following high speed impact in a suitable capture cell. Most likely, a single mission design would incorporate several different collection techniques.

On the basis of trajectory energy and spacecraft operational considerations, the coma sample return mission offers a relatively simpler and lower cost design than the planned comet rendezvous mission or subsequent nucleus sample return, yet it provides significant complementary science value. A proposed implementation scenario for such a mission involves an international effort wherein ESA would provide a second Giotto spacecraft (including its Comet Halley science instruments) and NASA would provide the sample collection experiment and the Earth return capsule. In support of this proposal, SAIC undertook a comprehensive study to identify and characterize mission opportunities for coma sample return for the known family of periodic comets, and also to determine the feasibility of flyby and sample return for new (first-apparition) comets as yet undiscovered.

Basic Characteristics of Mission Design. For an optimal free-return flyby, the round-trip time must be an integer number of years corresponding to resonance with Earth's orbit period. Table 2-17 lists the various possibilities of inward and outward-directed trajectories for trip times up to five years. For any given comet target, at least one and usually several types of free-return trajectories can be found. These are then judged as to suitability on the basis of their launch energy requirements, encounter geometry characteristics, and spacecraft design constraints (e.g., thermal control considerations may limit the perihelion and/or aphelion distance allowed).

The "ideal" target from the viewpoint of mission design has the following orbital geometry attributes:

1. Orbit node lies near perihelion;
2. Low inclination orbit;
3. Perihelion distance near 1 AU; and
4. Proper Earth location relative to the comet's perihelion position and time.

Table 2-17

CHARACTERISTICS OF OPTIMAL FREE-RETURN COMET FLYBY TRAJECTORIES

- ROUND-TRIP TIME MUST BE AN INTEGER NUMBER OF YEARS CORRESPONDING TO RESONANCE WITH EARTH'S ORBIT PERIOD

TRIP TIME^{y}/REVOLUTIONS	~ PERIHELION (AU)	~ APHELION (AU)
• INWARD-DIRECTED TRAJECTORIES		
1/1	0.90	1.10
2/3	0.53	1.00
3/4	0.65	1.00
4/5	0.72	1.00
5/6	0.77	1.00
• OUTWARD-DIRECTED TRAJECTORIES		
1/1	0.90	1.10
2/1	1.00	2.17
3/2	1.00	1.62
4/3	1.00	1.42
5/4	1.00	1.33

The results of such ideal geometry are: (1) the comet can be recovered (telescopically sighted) before launch; (2) low launch energy and reentry speed; (3) one-year round trip mission; (4) spacecraft remains in vicinity of 1 AU; (5) good Earth-based viewing and communications geometry at encounter; and (6) approach phase angle near 90°, which means maximum power to the Giotto spacecraft and partial lighting of the comet for on-board optical navigation.

It is recognized, of course, that the ideal geometry in all its aspects will be achievable only in rare circumstances. The present study sought to identify as many good mission opportunities as possible. In conducting this search, the inherent "science value" of the cometary target was not judged a priori but rather was left to scientists in some subsequent selection process.

The Giotto II Workshop held in January 1985 established certain constraints on the search for mission opportunities. These are as follows:

- 1988-1996 launches
- $C_3 \leq 50$ (km/sec)^2
- $V_{enc} \leq 15$ km/sec
- $r_{enc} \leq 1.6$AU.

The launch year range implied both the earliest and latest practical implementation using a second Giotto spacecraft and the desire to accomplish this mission prior to launching a more complex and costly nucleus sample return. The launch energy constraint implied both a lower cost launch vehicle/upper stage such as the Shuttle/TOS or the Ariane, and a practical upper bound on the Earth return velocity, i.e., $V_\infty \leq 7.1$ km/sec or atmospheric entry speed less than 13 km/sec. The relative encounter speed at comet flythrough should be as low as possible to assure intact sample collection. Based on experimental data, the upper bound was set at 15 km/sec although speeds under 10 km/sec would be preferable. Finally, the encounter distance constraint of 1.6 AU reflects both a power and thermal control limitation of the Giotto spacecraft.

Coma Sample Return Results. Table 2-18 lists relevant characteristics of the mission opportunities that were found to satisfy the abovementioned design constraints. These results are ordered by comet name and then by launch year when more than one mission opportunity was identified for a given comet. The encounter conditions include data and time relative to comet perihelion, approach speed, approach solar phase angle (0° is approach from the sunward direction so that the comet is fully illuminated), the Sun-Earth-target angle, the distances to the Sun and the Earth, the trajectory perihelion and aphelion distances, and the angle to Earth measured from the approach velocity vector.

To summarize these results, there are 25 short-period comets with a total of 44 mission opportunities between 1988 and 1996. There are 24 opportunities which have short return legs, a desirable characteristic from the standpoint of environmental control of the sample. Encounter dates encompass the range of 50 days before perihelion to 58 days after perihelion. Heliocentric encounter distances are no less than 0.93 AU except in one case where it is 0.68 AU. Flyby speeds lie in the range 7.9 to 14.9 km/sec, and do not exceed 10 km/sec in 13 cases. In 36 cases (82%), approach phase angles lie in the range $90° \pm 45°$, which represents a 70% or greater power output from the solar cells arranged around Giotto's cylindrical circumference (the spacecraft spin axis would be directed toward the comet). Earth-based viewing of the encounter is poor in about 17 cases (S-E-T < 30°) and good-to-excellent in 10 cases (S-E-T > 90°). Regarding launch conditions, the launch energy requirements are less than 30 $(km/sec)^2$ for 32 mission opportunities while high DLA (above 35°) requirements occur for only 9 opportunities. Concerning the round-trip time, there is only a single one-year mission opportunity, namely, Schwassman-Wachmann 3 launched in 1989. This mission, which has many desirable characteristics but is still not "perfect", is plotted in Figure 2-7. Most opportunities are found in the 3 or 4-year round-trip class. The scarcity of 2-year missions is due to the geometry constraint imposed by the 1.6 AU limit on encounter distance.

Table 2-19 lists additional mission opportunities that were identified after removal of the encounter distance constraint; these may be of some interest if the spacecraft is not restricted to the Giotto design. About half

Table 2-18

COMET COMA SAMPLE RETURN OPPORTUNITIES SATISFYING MISSION DESIGN CONSTRAINTS:
1988-96 LAUNCHES; $C_3 \leq 50$ $(km/sec)^2$; $V_{enc} \leq 15$ km/sec; $r_{enc} \leq 1.6$ AU

	LAUNCH CONDITIONS				ENCOUNTER CONDITIONS							
TARGET	ROUND-TRIP CLASS	C_3 $(km/sec)^2$	DLA (deg)	LAUNCH DATE	FLYBY DATE	SPEED (km/sec)	APPROACH PHASE (deg)	S-E-T ANGLE (deg)	SUN DIST (AU)	EARTH DIST (AU)	TRAJ. DIST. MIN-MAX(AU)	EARTH ASPECT ANGLE (deg)
AREND-RIGAUX	4^y	46.7	-23.9	20 SEP 88	15 OCT 91 (T_p+12^d)	11.5	85.4	62.7	1.44	1.60	0.94 - 1.49	69.7
	3^y	19.2	-24.1	27 JUN 89	29 NOV 91 (T_p+58^d)	13.8	135.5	79.0	1.57	1.43	1.01 - 1.61	31.7
	3^y	12.0	12.5	6 SEP 96	17 AUG 98 (T_p+35^d)	11.3	91.9	14.7	1.43	2.38	1.00 - 1.62	82.2
BOETHIN	3^y	11.5	10.6	20 JUL 95	11 APR 97 (T_p-20^d)	14.1	36.6	2.8	1.19	2.19	1.02 - 1.60	141.3
	3^y	17.3	49.7	11 AUG 95	21 MAY 97 (T_p+20^d)	8.4	87.2	2.3	1.19	2.20	1.00 - 1.62	91.9
C-G	5^y	5.3	-34.9	20 MAY 95	2 JAN 96 (T_p-15^d)	9.5	77.0	80.6	1.31	1.05	1.00 - 1.32	144.5
CLARK	3^y	40.4	17.6	7 DEC 92	16 APR 95 (T_p-45^d)	9.1	85.8	108.5	1.61	0.98	0.93 - 1.69	64.5
D'ARREST	4^y	16.0	1.8	25 JAN 92	28 JUL 95 (T_p+1^d)	14.0	109.8	134.2	1.35	0.42	0.95 - 1.47	56.6
	3^y	11.7	0.9	18 NOV 92	27 JUL 95 (T_p)	14.0	116.3	133.2	1.35	0.43	0.98 - 1.64	53.7
DUTOIT-HARTLEY	4^y	8.4	-17.7	12 NOV 90	23 JUL 92 (T_p-30^d)	13.1	34.3	28.7	1.25	2.04	0.99 - 1.44	168.0
	4^y	39.3	-19.4	18 MAR 91	12 OCT 92 (T_p+50^d)	7.9	113.8	26.7	1.34	2.15	0.90 - 1.53	85.5
FINLAY	4^y	48.1	-4.1	5 MAY 92	25 APR 95 (T_p-10^d)	12.3	37.9	20.7	1.04	1.92	0.91 - 1.51	121.8
	4^y	30.7	-2.9	2 NOV 93	14 MAY 95 (T_p+10^d)	13.3	114.1	18.2	1.05	1.96	0.67 - 1.06	48.4
FORBES	3^y	13.2	13.2	4 JAN 97	26 JUN 99 (T_p+50^d)	13.4	140.4	92.4	1.56	1.14	0.98 - 1.64	20.1
GALE	3^y	11.4	20.1	4 SEP 91	7 NOV 92 (T_p-40^d)	10.0	71.0	7.8	1.33	2.30	1.01 - 1.61	113.2
GRIGG-SKJELLERUP	5^y	6.7	-22.3	20 MAY 91	25 JUL 92 (T_p)	14.4	89.3	44.7	0.99	1.42	0.99 - 1.33	102.0
	4^y	24.1	-10.9	20 JUL 96	3 SEP 97 (T_p)	14.7	103.6	25.5	1.00	1.81	0.96 - 1.46	84.0
HANEDA-CAMPOS	3^y	18.1	-10.2	1 JUL 89	24 APR 91 (T_p+16^d)	7.9	69.5	3.6	1.24	2.24	1.01 - 1.61	107.8
	3^y	29.1	41.0	17 JAN 90	19 MAR 91 (T_p-20^d)	8.3	110.3	3.3	1.25	2.24	0.96 - 1.66	67.5
HMP	2^y	36.7	16.1	26 APR 94	15 JAN 96 (T_p+20^d)	11.8	140.4	4.4	0.68	0.31	0.51 - 1.02	141.6
HOWELL	3^y	20.9	-35.1	16 FEB 91	11 MAR 93 (T_p-10^d)	9.6	70.0	41.9	1.62	2.21	0.97 - 1.65	87.6
JACKSON-NEUJMIN	4^y	39.7	-6.1	18 FEB 95	13 SEP 95 (T_p-23^d)	13.7	52.4	155.9	1.41	0.43	0.91 - 1.51	144.3

Table 2-18 (cont'd.)

COMET COMA SAMPLE RETURN OPPORTUNITIES SATISFYING MISSION DESIGN CONSTRAINTS: 1988-96 LAUNCHES; $C_3 \leq 50$ (km/sec)^2; $V_{enc} \leq 15$ km/sec; $r_{enc} \leq 1.6$ AU

	LAUNCH CONDITIONS				ENCOUNTER CONDITIONS							
TARGET	ROUND-TRIP CLASS	C_3 (km/sec)^2	DLA (deg)	LAUNCH DATE	FLYBY DATE	SPEED (km/sec)	APPROACH PHASE (deg)	S-E-T ANGLE (deg)	SUN DIST (AU)	EARTH DIST (AU)	TRAJ. DIST. MIN-MAX(AU)	EARTH ASPECT ANGLE (deg)
KOWAL 2	2^y	26.6	13.6	18 AUG 91	22 DEC 91 (T_p-10^d)	14.5	45.2	130.8	1.50	0.66	1.01 - 2.16	143.6
	4^y	7.8	-15.7	2 JUL 96	30 APR 98 (T_p-12^d)	12.4	67.6	15.9	1.35	2.29	1.02 - 1.41	120.0
PONS-WINNECKE	5^y	21.4	47.2	2 NOV 88	17 SEP 89 (T_p+28^d)	14.9	122.8	68.8	1.31	1.27	0.97 - 1.35	84.2
SCHUSTER	3^y	19.8	-52.8	10 APR 90	26 SEP 92 (T_p+20^d)	12.6	117.1	85.0	1.55	1.28	1.00 - 1.62	44.1
SCHWASSMAN-WACHMANN 3	1^y	12.4	-18.6	14 DEC 89	4 MAY 90 (T_p-14^d)	13.9	49.5	71.0	0.96	0.43	0.88 - 1.12	62.4
	3^y	14.9	-4.9	17 APR 93	18 SEP 95 (T_p-4^d)	13.5	105.8	42.0	0.93	1.40	0.64 - 1.01	113.5
	5^y	23.4	-6.7	30 JUL 94	11 SEP 95 (T_p-11^d)	10.8	65.5	40.9	0.95	1.44	0.95 - 1.37	130.8
TEMPEL 1	3^y	10.9	-4.7	14 JAN 94	2 JUL 94 (T_p)	10.4	62.5	106.0	1.49	0.85	0.98 - 1.64	145.4
TEMPEL 2	4^y	10.1	13.4	25 FEB 88	21 AUG 88 (T_p-27^d)	11.1	57.6	97.6	1.41	0.86	0.98 - 1.44	149.6
	3^y	24.5	24.2	4 MAR 88	28 JUL 88 (T_p-50^d)	14.2	35.6	108.7	1.48	0.80	0.98 - 1.62	161.8
	3^y	11.1	-24.4	3 MAR 92	23 FEB 94 (T_p-21^d)	11.8	53.5	21.7	1.50	2.37	0.99 - 1.63	115.4
TRITTON	4^y	30.7	-25.7	9 APR 88	4 JUL 90 (T_p-3^d)	9.8	101.5	9.5	1.44	2.43	0.95 - 1.47	71.7
	3^y	34.3	57.8	25 JUL 88	6 AUG 90 (T_p+20^d)	8.1	83.5	14.2	1.47	2.44	0.98 - 1.64	86.9
	4^y	28.7	-26.1	15 APR 93	31 OCT 96 (T_p-3^d)	9.8	100.2	88.0	1.44	1.07	0.96 - 1.46	43.5
	3^y	13.4	-27.0	10 JUN 94	6 DEC 96 (T_p+37^d)	12.5	135.4	102.3	1.48	0.92	1.01 - 1.61	21.0
TSUCHINSHAN	3^y	24.6	47.4	26 SEP 89	30 AUG 91 (T_p)	11.0	65.2	22.7	1.50	2.38	0.99 - 1.63	103.0
TGK	4^y	48.2	24.5	3 DEC 93	20 JUL 95 (T_p-8^d)	12.8	46.8	39.3	1.07	1.64	0.92 - 1.50	153.0
WILD 2	3^y	24.0	-15.7	9 SEP 88	24 JAN 91 (T_p+38^d)	9.8	121.9	60.6	1.62	1.70	0.99 - 1.63	24.4
	3^y	21.8	31.9	7 OCT 88	10 NOV 90 (T_p-37^d)	10.2	56.4	46.0	1.62	2.14	0.98 - 1.64	98.1
	3^y	30.9	40.5	4 DEC 96	28 MAY 97 (T_p+21^d)	8.8	82.4	84.8	1.60	1.33	0.95 - 1.67	135.5
WOLF-HARRINGTON	3^y	16.7	-15.0	19 JUN 90	24 MAR 91 (T_p-11^d)	11.6	89.9	45.4	1.61	2.15	1.00 - 1.62	105.5
	3^y	49.7	41.5	30 APR 95	25 OCT 97 (T_p+26^d)	11.5	119.1	77.9	1.60	1.48	0.97 - 1.65	37.7

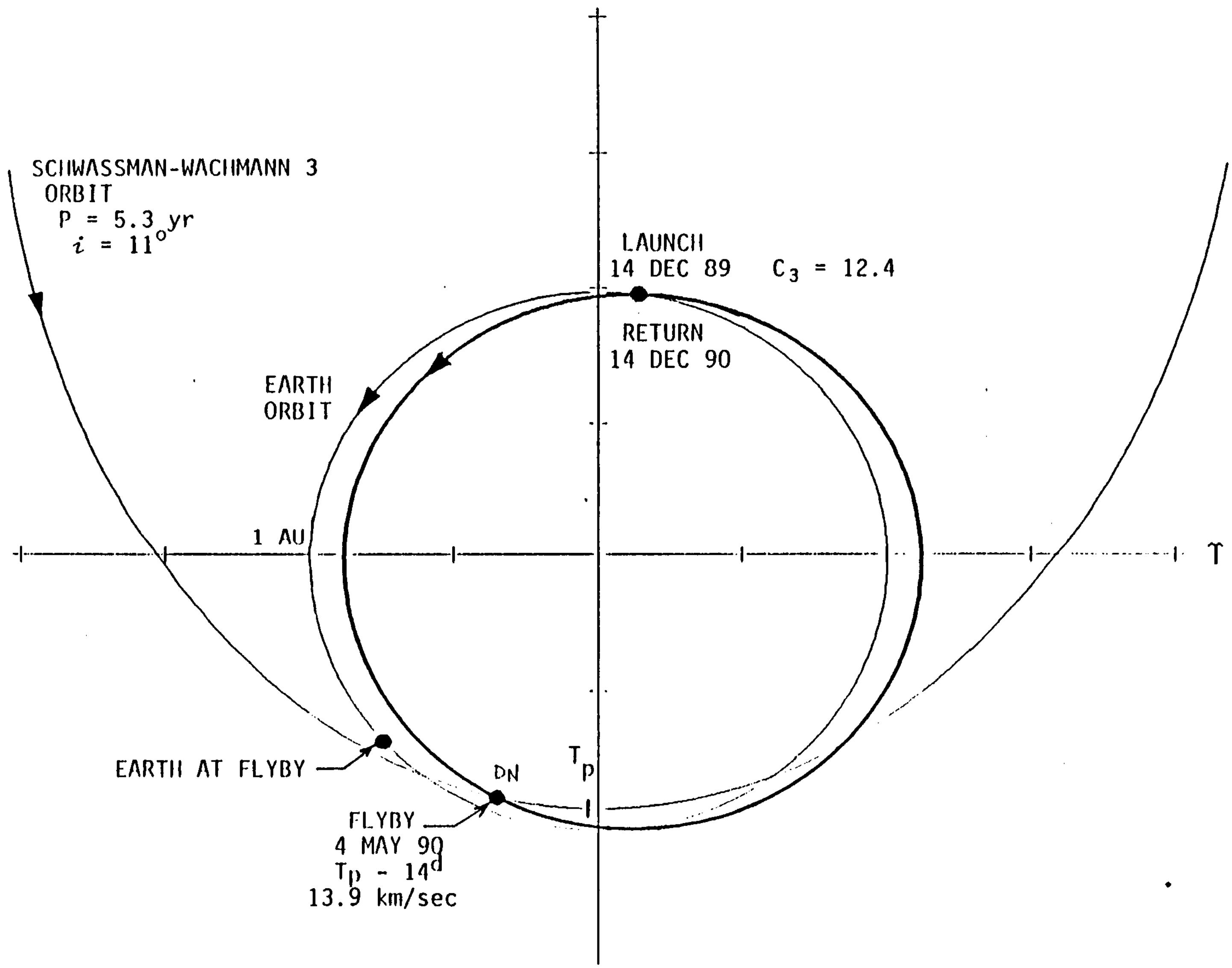


Figure 2-7. TRAJECTORY PROFILE FOR SCHWASSMAN-WACHMANN 3 COMA SAMPLE RETURN

Table 2-19

ADDITIONAL COMET COMA SAMPLE RETURN OPPORTUNITIES

TARGET	ROUND-TRIP CLASS	C_3 $(km/sec)^2$	DLA (deg)	LAUNCH DATE	FLYBY DATE	SUN DIST. (AU)	SPEED (km/sec)
BROOKS 2	2^y	36.1	-18.7	20 FEB 93	13 JUL 94	1.90	8.8
	3^y	48.0	-4.6	25 JAN 92	1 SEP 94	1.84	14.0
CLARK	2^y	33.8	53.6	11 OCT 93	31 MAY 95	1.55	11.7
DEVICO-SWIFT	2^y	43.6	-37.8	1 MAR 94	14 MAY 95	2.17	9.2
DUTOIT-NEUJMIN	3^y	48.4	-33.5	6 DEC 88	18 OCT 89	1.72	9.1
HOLMES	2^y	45.1	-47.7	31 JAN 92	19 FEB 93	2.21	9.6
METCALF	3^y	29.3	-46.0	10 JAN 90	18 DEC 90	1.61	12.0
NEUJMIN 3	2^y	44.7	8.3	25 FEB 93	4 OCT 93	2.04	12.2
PETERS-HART	3^y	39.3	-18.1	12 NOV 89	10 AUG 90	1.68	14.9
TEMPEL-SWIFT	3^y	20.0	-44.8	3 APR 93	9 SEP 95	1.60	11.5
WILD 2	2^y	26.2	27.0	31 OCT 96	28 MAR 97	1.63	14.7

CONSTRAINTS: 1988-96 LAUNCHES, $C_3 \leq 50$ $(km/sec)^2$, $V_{enc} \leq 15$ km/sec

of these additional opportunities are of the 2-year round-trip class. A fairly good example here is the Brooks 2 mission launched in 1993; the trajectory profile is shown in Figure 2-8. Table 2-20 lists all the cases found for which the encounter speed is under 10 km/sec.

In summary, there are a significant number of coma sample return mission opportunities which have reasonably good, if not ideal, design characteristics. This result should allow ample freedom of selection by the science community and NASA program planners.

New Comet Flyby and Sample Return. A previous SAIC study of new (first-apparition) comet flyby opportunities was updated to account for Giotto II constraints. The study approach is three-fold: (1) determine a set of comet candidates from both historical discovery records and predicted intrinsic populations; (2) develop reasonable constraints for mission searches; and (3) perform mission searches expressing results in terms of acceptable opportunities per year. Set A candidates consist of 134 first-apparition comets discovered between 1945 and 1978 taken from Marsden's catalog of cometary orbits. Set B candidates are selected by random sampling of Everhart's intrinsic distribution, which expects that 48 new comets will come to perihelion each year, of which approximately 36 could be discovered by a dedicated search program.

Table 2-21 lists the various discovery and mission constraints that were imposed on the problem. The Giotto II review limits the acceptable launch energy to $C_3 \leq 50$ (km/sec)^2, and further constrains the encounter distance to the range 0.7 - 1.6 AU and the approach phase angle to the range 50° - 130°.

Case study results are presented in Table 2-22. Consider, for example, the more restrictive requirement that the comet must be visible from Earth at the time of encounter. From the previous study of this problem, we found that photographic discovery at 15th magnitude or brighter is essential if the mission opportunity frequency is to be at all practical from the standpoint of mission planning. Thus, based on the historical set of comets, the expected number of mission opportunities is 0.88 per year. Monte Carlo sampling of the

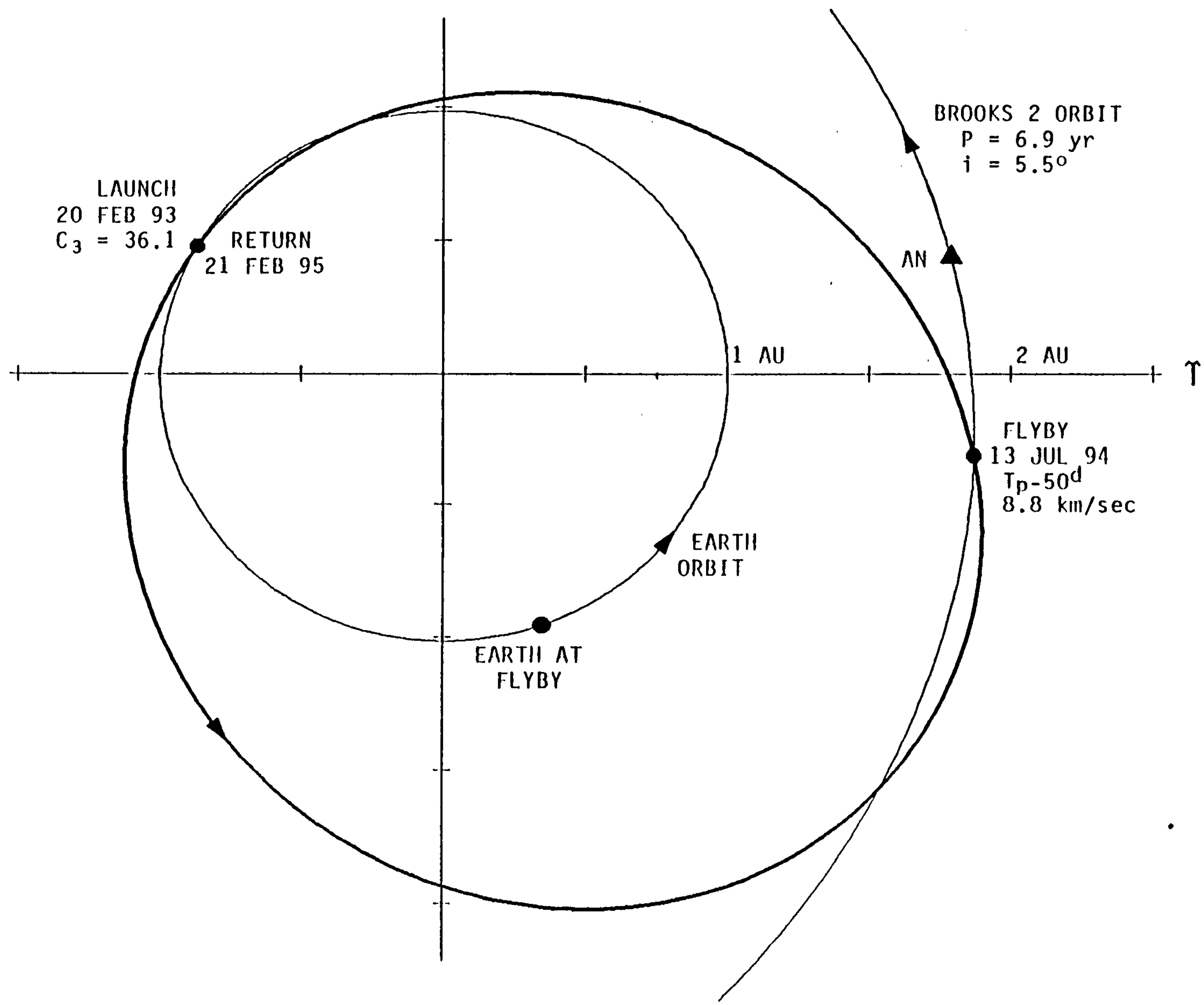


Figure 2-8. TRAJECTORY PROFILE FOR BROOKS 2 COMA SAMPLE RETURN

Table 2-20

COMET COMA SAMPLE RETURN OPPORTUNITIES SATISFYING MISSION DESIGN CONSTRAINTS:

1988-96 Launches; $C_3 \leq 50$ km²/sec²; $\boxed{V_{enc} < 10 \text{ km/sec}}$

LAUNCH	COMET	RND-TRP CLASS	FLYBY DATE	RETURN	C_3 (km^2/sec^2)	DLA (deg)	SUN Dist(AU)	SPEED (km/sec)
JUL 1988	TRITTON	3	8/06/90 (T_p+20^d)	JUL 91	34.3	57.8	1.47	8.1
SEP 1988	WILD 2	3	1/24/91 (T_p+38^d)	SEP 91	24.0	-15.7	1.62	9.8
DEC 1988	DUTOIT-NEUJMIN	3	10/18/89 (T_p)	DEC 91	48.4	-33.5	1.72	9.1
JUL 1989	HANEDA-CAMPOS	3	4/24/91 (T_p+16^d)	JUL 92	18.1	-10.2	1.24	7.9
JAN 1990	HANEDA-CAMPOS	3	3/19/91 (T_p-20^d)	JAN 93	29.1	41.0	1.25	8.3
FEB 1991	HOWELL	3	3/11/93 (T_p-10^d)	FEB 94	20.9	-35.1	1.62	9.6
MAR 1991	DUTOIT-HARTLEY	4	10/12/92 (T_p+50^d)	MAR 95	39.3	-19.4	1.34	7.9
JAN 1992	HOLMES	2	2/19/93 (T_p-50^d)	JAN 94	45.1	-47.7	2.21	9.6
DEC 1992	CLARK	3	4/16/95 (T_p-45^d)	DEC 95	40.4	17.6	1.61	9.1
FEB 1993	BROOKS 2	2	7/13/94 (T_p-50^d)	FEB 95	36.1	-18.7	1.90	8.8
APR 1993	TRITTON	4	10/31/96 (T_p-3^d)	APR 97	28.7	-26.1	1.44	9.8
MAR 1994	DEVICO-SWIFT	2	5/14/95 (T_p-40^d)	MAR 96	43.6	-37.8	2.17	9.2
MAY 1995	C-G	5	1/02/96 (T_p-15^d)	MAY 00	5.3	-34.9	1.31	9.5
AUG 1995	BOETHIN	3	5/21/97 (T_p+20^d)	AUG 98	17.3	49.7	1.19	8.4
DEC 1996	WILD 2	3	5/28/97 (T_p+21^d)	DEC 99	30.9	40.5	1.60	8.8

Table 2-21

DISCOVERY AND MISSION CONSTRAINTS

BRIGHTNESS	15TH MAGNITUDE OR BRIGHTER
VISIBLITY	> 2 HOURS OF DARK SKY BETWEEN $\pm$ 50° LATITUDE
ORBIT DETERMINATION	20 DAYS OF ACCEPTABLE VISIBILITY
LAUNCH PREPARATION	$\geq$ 30 DAYS AFTER O.D., i.e. $\geq$ 50 DAYS AFTER DISCOVERY
LAUNCH ENERGY	$\leq$ 130 KM^2/SEC^2 C_3 (ORIGINAL STUDY)
	$\leq$ 50 KM^2/SEC^2 (GIOTTO II REVIEW)
ENCOUNTER CONSTRAINT	OBSERVABLE FROM EARTH

Table 2-22

NEW COMET FLYBY MISSION OPPORTUNITIES - CASE STUDY RESULTS

Case Study	No Visibility Constraint		Visibility Constraint*	
	Missions/Year	Avg C_3	Missions/Year	Avg C_3
A. Using Discovered Comet Sample				
1. 134 Comets - Actual Discovery Date	0.21	86	0.15	74
2. 134 Comets - Predicted Photographic Discovery at 15th Magnitude	1.29	61	0.88	68
B. Using Intrinsic Comet Distributions with Photographic Discovery ($q \leq 2$ AU, $M_A \leq 12$)				
3. 94 Comet Sample with Intrinsic Weighting	4.76	--	4.06	--
4. Monte Carlo Simulation	4.98	70	3.76	72
C. Giotto II Constraints ($0.7 \leq r_{enc} \leq 1.6$ AU; $50^o \leq \phi \leq 130^o$; $C_3 \leq 50$)				
Case 2.	0.38	25.4	0.35	29.4
Case 4.	0.98	23.6	0.83	22.2

* Earth-based telescopic visibility at comet encounter

intrinsic comet distribution yields a significant increase of opportunity to about four mission possibilities per year. When the Giotto constraints are imposed, the above opportunity measures decreases to 0.35 and 0.83 per year, respectively.

Table 2-23 is a statistical summary of the mission characteristics for the Giotto review. Figure 2-9 shows the probability of an acceptable launch opportunity occurrence as a function of the number of months (waiting period) after launch readiness. For a 12-month wait the probability is only 56%, but this increases to a more viable value of 80% at 24 months and 91% at 36 months.

The final topic considered here is the possibility of coma sample return from a new comet. SAIC examined a limited set of 33 opportunities for which successful flyby missions were found using the Giotto-type constraints. Somewhat surprisingly, it was found that 29 of these 33 cases (88%) were also good sample return opportunities. Of course, the caveat is that the encounter speed is much higher (42 km/sec on average) than missions to short-period comets. Table 2-24 lists the mission characteristics of these 29 cases.

2.7 Advanced Mission and Technology Concepts

The purpose of this task area is to identify future technology needs of planetary exploration in the time period of 10 to 30 years from the present. This technology need is expressed principally within the framework of advanced vehicle and propulsion systems and advanced mission concepts that require such systems. Two separate subtasks were performed in this area of analysis: (1) an assessment of solar electric propulsion mission applications, performed in support of the ESA/NASA Primitive Bodies Science Study Group; and (2) development of an automated science instrument database as a tool to enhance SAIC's advanced planetary mission studies. Results for each of these subtasks are described in the extended summaries that follow.

2.7.1 SEP Mission Applications Assessment

Background. More than twenty-five years have passed since electric propulsion systems were first seriously proposed for Earth-orbital and

Table 2-23

STATISTICAL SUMMARY OF NEW COMET FLYBY MISSIONS - GIOTTO II REVIEW

- MONTE CARLO SAMPLING OF INTRINSIC POPULATION DISTRIBUTIONS
- GIOTTO II CONSTRAINTS
- EARTH-BASED VISIBILITY AT ENCOUNTER
- MISSION SUCCESS FREQUENCY: 1.7% ≡ 0.83 MISSIONS/YEAR

	MIN	MEAN	MAX
LAUNCH (T_L-T_P), days	-350.0	-103.1	-20.0
LAUNCH C_3, $(km/sec)^2$	1.4	22.1	49.6
LAUNCH |DLA|, deg	0.1	30.2	84.9
FLIGHT TIME, days	70.0	134.7	330.0
ENCOUNTER (T_A-T_P), days	-20.0	31.6	70.0
SPEED, km/sec	8.9	42.4	62.1
PHASE ANGLE, deg	70.3	106.2	129.0
SOLAR DISTANCE, AU	0.8	1.2	1.6
EARTH DISTANCE, AU	0.1	0.5	1.4
MAGNITUDE	-0.6	7.3	12.3
VISIBILITY, hrs	2.2	6.7	11.9

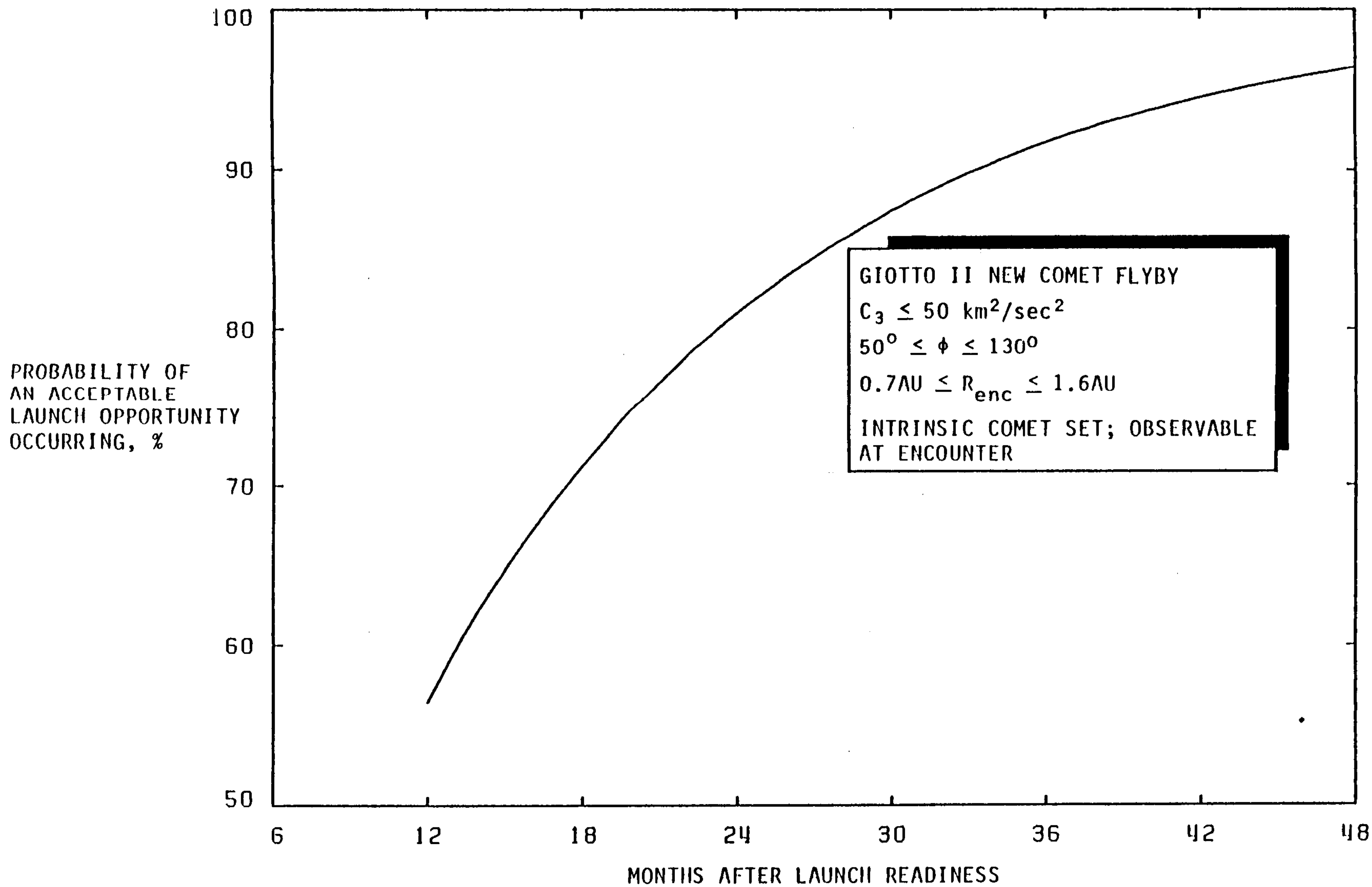

PROBABILITY OF AN ACCEPTABLE LAUNCH OPPORTUNITY OCCURRING, %
100
90
80
70
60
50
6
12
18
24
30
36
42
48
MONTHS AFTER LAUNCH READINESS
GIOTTO II NEW COMET FLYBY
$C_3 \leq 50$ km^2/sec^2
$50^o \leq \phi \leq 130^o$
$0.7AU \leq R_{enc} \leq 1.6AU$
INTRINSIC COMET SET; OBSERVABLE AT ENCOUNTER

Figure 2-9.

Table 2-24

NEW COMET COMA SAMPLE RETURN EXAMPLES SATISFYING GIOTTO-TYPE MISSION DESIGN CONSTRAINTS

$C_3 \leq 50\ (km/sec)^2;\ 0.7 \leq r_{enc} \leq 1.6$ AU; $50^o \leq \phi \leq 130^o$

	LAUNCH CONDITIONS				ENCOUNTER CONDITIONS							
TARGET	ROUND-TRIP CLASS	C_3 (km/sec)	DLA (deg)	LAUNCH DATE	FLYBY DATE	SPEED (km/sec)	APPROACH PHASE (deg)	S-E-T ANGLE (DEG)	SUN DIST (AU)	EARTH DIST (AU)	TRAJ. DIST. MIN-MAX(AU)	EARTH ASPECT ANGLE (DEG)
1945 III	4^Y	47.6	-34.4	T_d+80^d	T_p+60^d	53.2	105.8	111.6	1.41	.68	.89 - 1.52	76.7
1955 V	1^Y	14.3	15.9	T_d+99^d	T_p+7^d	62.8	93.0	61.0	.90	.37	.89 - 1.11	136.9
1959 IV	4^Y	27.0	-18.6	T_d+56^d	T_p+57^d	26.8	120.3	96.1	1.46	.96	.93 - 1.49	66.9
1960 II	1^Y	48.5	79.8	T_d+102^d	T_p+42^d	63.6	117.6	92.6	1.05	.26	.95 - 1.05	51.0
1961 VIII	1^Y	8.46	-15.2	T_d+82^d	T_p+30^d	70.7	119.7	68.9	.95	.15	.95 - 1.05	138.0
1964 VIII	5^Y	29.4	-27.9	T_d+113^d	T_p+12^d	78.0	100.8	33.5	.85	.20	.72 - 1.05	78.8
1964 IX	5^Y	34.2	-47.1	T_d+50^d	T_p-30^d	36.1	70.5	109.4	1.34	.60	.90 - 1.40	102.0
1968 V	3^Y	25.2	-32.2	T_d+50^d	T_p+4^d	35.4	80.4	152.8	1.24	.24	.96 - 1.66	100.2
1975 X	5^Y	8.3	-44.8	T_d+90^d	T_p+18^d	65.5	104.6	35.5	.90	.11	.75 - 1.02	63.3
RANDOM 1	5^Y	46.4	-37.6	T_d+269^d	T_p	19.7	88.4	58.8	1.01	1.07	.75 - 1.02	52.6
RANDOM 2	2^Y	28.5	11.1	T_d+95^d	T_p+61^d	45.8	103.0	150.1	1.41	.47	1.01 - 2.16	61.5
RANDOM 3	2^Y	30.6	-31.5	T_d+50^d	T_p+71^d	39.3	118.6	131.8	1.54	.68	1.01 - 2.16	43.1
RANDOM 4	2^Y	33.1	7.3	T_d+89^d	T_p+63^d	51.9	105.8	153.9	1.39	.40	1.00 - 2.17	58.1
RANDOM 5	3^Y	35.8	39.0	T_d+142^d	T_p+61^d	35.3	113.2	110.9	1.44	.76	1.00 - 1.61	62.1
RANDOM 6	4^Y	24.5	21.6	T_d+50^d	T_p+22^d	21.6	114.0	81.6	.97	.19	.94 - 1.48	66.2
RANDOM 7	3^Y	25.1	-28.7	T_d+93^d	T_p+55^d	25.4	124.1	132.0	1.33	.45	1.01 - 1.61	68.4
RANDOM 8	3^Y	19.3	-17.6	T_d+50^d	T_p+54^d	33.6	110.5	124.0	1.37	.55	1.00 - 1.62	66.0

Table 2-24 (cont'd.)

NEW COMET COMA SAMPLE RETURN EXAMPLES SATISFYING GIOTTO-TYPE MISSION DESIGN CONSTRAINTS (Cont'd.)

$C_3 \leq 50\ (km/sec)^2$; $0.7 \leq r_{enc} \leq 1.6$ AU; $50^o \leq \phi \leq 130^o$

	LAUNCH CONDITIONS				ENCOUNTER CONDITIONS							
TARGET	ROUND-TRIP CLASS	C_3 (km/sec)	DLA (deg)	LAUNCH DATE	FLYBY DATE	SPEED (km/sec)	APPROACH PHASE (deg)	S-E-T ANGLE (DEG)	SUN DIST (AU)	EARTH DIST (AU)	TRAJ. DIST. MIN-MAX(AU)	EARTH ASPECT ANGLE (DEG)
RANDOM 9	5^Y	25.5	44.3	T_d+50^d	T_p-20^d	49.5	81.3	91.1	1.03	.22	.72 - 1.05	43.2
RANDOM 10	4^Y	46.3	-.9	T_d+130^d	T_p+20^d	36.4	94.8	81.9	1.54	1.32	.87 - 1.55	71.2
RANDOM 11	5^Y	25.7	-35.0	T_d+50^d	T_p+19^d	24.0	124.7	88.9	1.03	.25	.69 - 1.08	114.0
RANDOM 12	1^Y	35.9	-13.1	T_d+57^d	T_p+30^d	20.8	125.0	99.0	1.21	.53	.78 - 1.22	92.1
RANDOM 13	2^Y	41.6	17.5	T_d+104^d	T_p+72^d	50.3	101.6	125.3	1.57	.75	1.00 - 2.18	51.0
RANDOM 14	1^Y	15.5	6.2	T_d+57^d	T_p-10^d	20.2	76.5	108.9	1.12	.28	.88 - 1.12	112.9
RANDOM 15	1^Y	29.0	13.9	T_d+113^d	T_p+10^d	33.9	91.8	128.2	1.12	.21	.83 - 1.17	80.8
RANDOM 16	5^Y	6.6	11.1	T_d+71^d	T_p+37^d	64.2	124.6	75.9	.99	.07	.77 - 1.00	49.5
RANDOM 17	4^Y	18.2	-10.3	T_d+50^d	T_p+40^d	26.0	116.9	137.1	1.15	.19	.95 - 1.48	76.1
RANDOM 18	5^Y	21.9	-65.3	T_d+87^d	T_p+38^d	61.8	105.1	62.3	1.26	1.37	1.00 - 1.32	33.2
RANDOM 19	1^Y	33.9	27.3	T_d+98^d	T_p+30^d	60.5	126.9	52.7	.85	.27	.84 - 1.16	121.8
RANDOM 20	3^Y	11.7	-8.5	T_d+155^d	T_p+30^d	68.5	100.2	115.5	1.05	.07	1.01 - 1.61	142.2
AVERAGE		27.5	26.3	T_d+89^d	T_p+30^d	44.2	105.5	99.0	1.19	.47		78.6

planetary mission applications. A considerable amount of work has been accomplished during this period in the areas of trajectory optimization theory and computation, mission performance and operations analysis, hardware development and testing of components and subsystems, vehicle design, and technology readiness planning. Much of this work was performed by a wide spectrum of government and private industry organizations during the "heyday" of the U.S. Space Program (1965-1975). The initial focus on nuclear electric power sources (NEP) was soon transferred to solar electric systems (SEP) on the basis of technology readiness. Electric propulsion applications became concentrated on automated, scientific exploration of the solar system. The first such mission has yet to be performed!

SEP technology in the U.S. was brought to a state of near-readiness as a flight system by the late 1970's. The first application was to be the Comet Halley Flyby/Tempel 2 Rendezvous mission. Development was then deferred for reasons of funding limitations and a reduced scope of potential mission applications, particularly in the Earth-orbital payload delivery arena. Planetary mission applications, also subject to budgetary constraints, were not perceived to be a sufficient driver for further development at that time.

In 1983 the Solar System Exploration Committee (SSEC) of the NASA Advisory Council recommended a Core Program of planetary exploration through the year 2000. This program is designed to accomplish high priority science missions at moderate funding levels - hence the minimization of new technology requirements. The candidate missions in the SSEC-recommended Core Program do not require SEP availability for the most part. However, SEP performance potential was recognized and considered useful as a possible enhancing option for later implementation, particularly for asteroid rendezvous missions. The SSEC has also fashioned an Augmented Program (the report is soon to be published) containing technologically challenging advanced missions that will probably require large funding levels and might be undertaken as national priorities permit. Comet nucleus sample return is one such mission for which SEP has been identified as one of the enabling options. NEP technology is also noted as having high-performance potential for augmentation-type missions to the outer planets.

The current decade has seen heightened European interest in planetary exploration missions as well as SEP technology. One concept matching mission and electric propulsion is AGORA which would be designed to rendezvous with several Mainbelt asteroids. The AGORA study undertaken by the European Space Agency (ESA) includes a significant effort with industry to evaluate and advance electric propulsion technology (ion thrusters, solar array, etc.) whose history of development in Europe dates back to the early 1970's. ESA has recently published a long-term planning document, Space Science Horizon 2000, which includes planetary exploration as a major element (cornerstone) of its balanced program. The Comet Nucleus Sample Return mission has been identified as the primary mission candidate for ESA's cornerstone planetary project.

Both NASA and ESA are cognizant of the relationship between their space science programs and the benefits of coordination and cooperation among national agencies. Missions such as the Saturn Orbiter/Titan Probe (Cassini) and a variety of comet and asteroid exploration concepts are currently being considered by joint ESA/NASA science study groups. In this context, it seems reasonable to raise the issue of possible cooperative development of a SEP flight system for those missions undertaken jointly in some sense.

Study Objectives. The task reported herein set out to assess, for Code EL-NASA Headquarters, the usefulness of solar electric propulsion for achieving future exploration goals both within and beyond the Core Program framework. Usefulness in the context of program planning implies an understanding of the performance capabilities of SEP over a range of mission applications, and comparisons with alternative systems for mass delivery. Performance trade-off data on payload mass, flight time, and SEP power level were developed for a variety of missions including primitive body rendezvous and sample return, Mercury orbiter, and outer planet orbiters. The main focus of this work was on primitive body missions and was performed (under Code EL direction) in support of the ESA/NASA Primitive Bodies Science Study Group.

SEP System Characteristics. For purposes of performance calculations, available design data for the European SEP and the U.S. ASEP (A = advanced)

concepts were utilized to derive mass scaling relationships. This scaling is shown in Figure 2-10 as a function of the maximum input power to the power conditioning unit for both flat array and concentrated array designs. The propulsion system dry mass includes the solar array, power conditioning and thruster units, propellant tank and feed subsystems, electrical harness, thermal control, structure, and other relevant control and interface elements. Input power for each PCU/thruster unit at nominal operating conditions is taken as 4.0 kw for the RIT-35 system and 6.9 kw for the U.S. 30-cm ion engine. Figure 2-10 indicates the number of installed thruster units at various total power levels assuming that one thruster is always held in spare for purposes of increased reliability. At P_0 approximately equal to 20 kw, the European SEP would have six thrusters whereas the U.S. ASEP would have four thrusters installed. Propulsion system mass for these example cases is 1000 kg and 720 kg, respectively, assuming a flat array design. For the concentrated array, a trough design is assumed with an effective concentration factor of 1.65.

Figure 2-11 shows the required solar array power as a function of PCU input power assuming a 10% degradation factor (taken at beginning of life) and 0.5 kw auxiliary power for operating spacecraft subsystems. Figure 2-12 describes the power characteristic vs. heliocentric distance which was used for performance calculations in this section. Generally speaking, the SEP is not operated beyond 3.5 AU because of the low power available; the actual cut-off point may be somewhat lower depending on the thruster throttling capability as well as the minimum number of operating thrusters (one or two, depending upon attitude control strategy). The concentrated array profile shown here assumes the same array size as the flat array case, i.e., the initial excess power due to concentration allows constant power operation out to 1.28 AU.

Thruster-specific impulse at nominal operating conditions is taken as 3560 sec, and the overall system power efficiency (jet power/input power) is 68.2 percent. These values are used for both the European and the U.S. systems; actual differences exist but are not thought to be too significant for purposes of describing mission performance capability. Although results

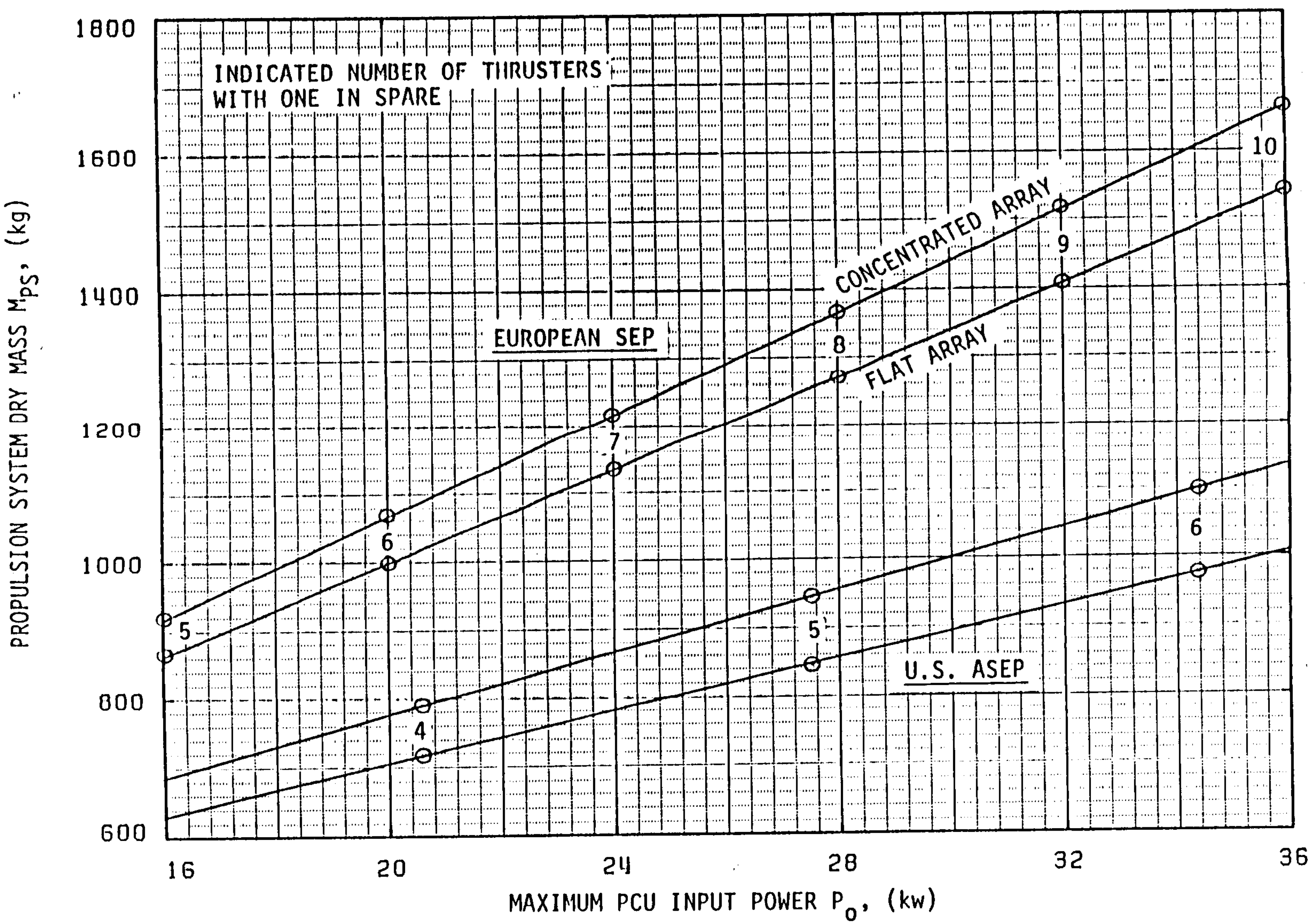


Figure 2-10. SEP SYSTEM MASS vs DESIGN POWER LEVEL

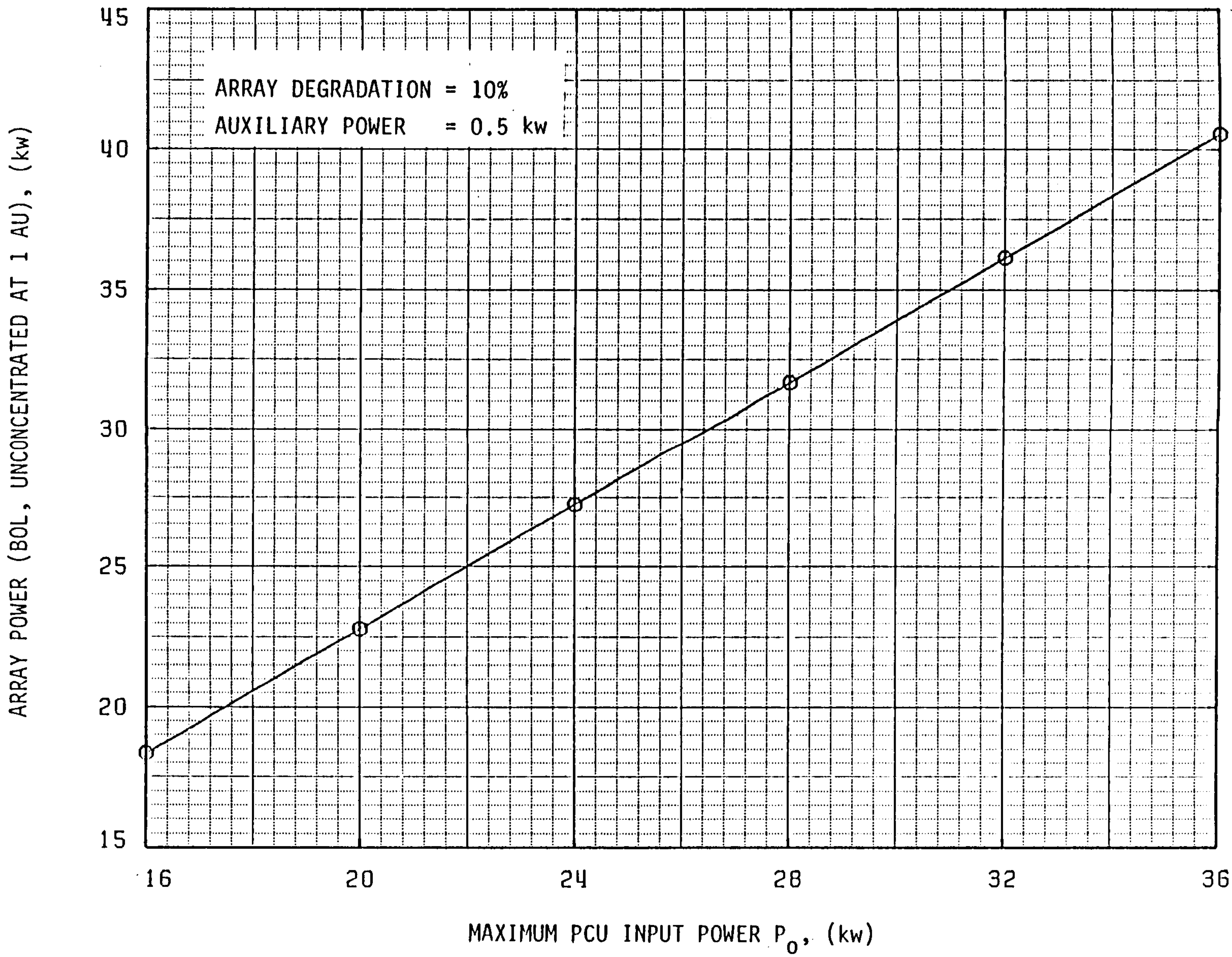


Figure 2-11. SOLAR ARRAY SIZED TO MATCH PROPULSION POWER

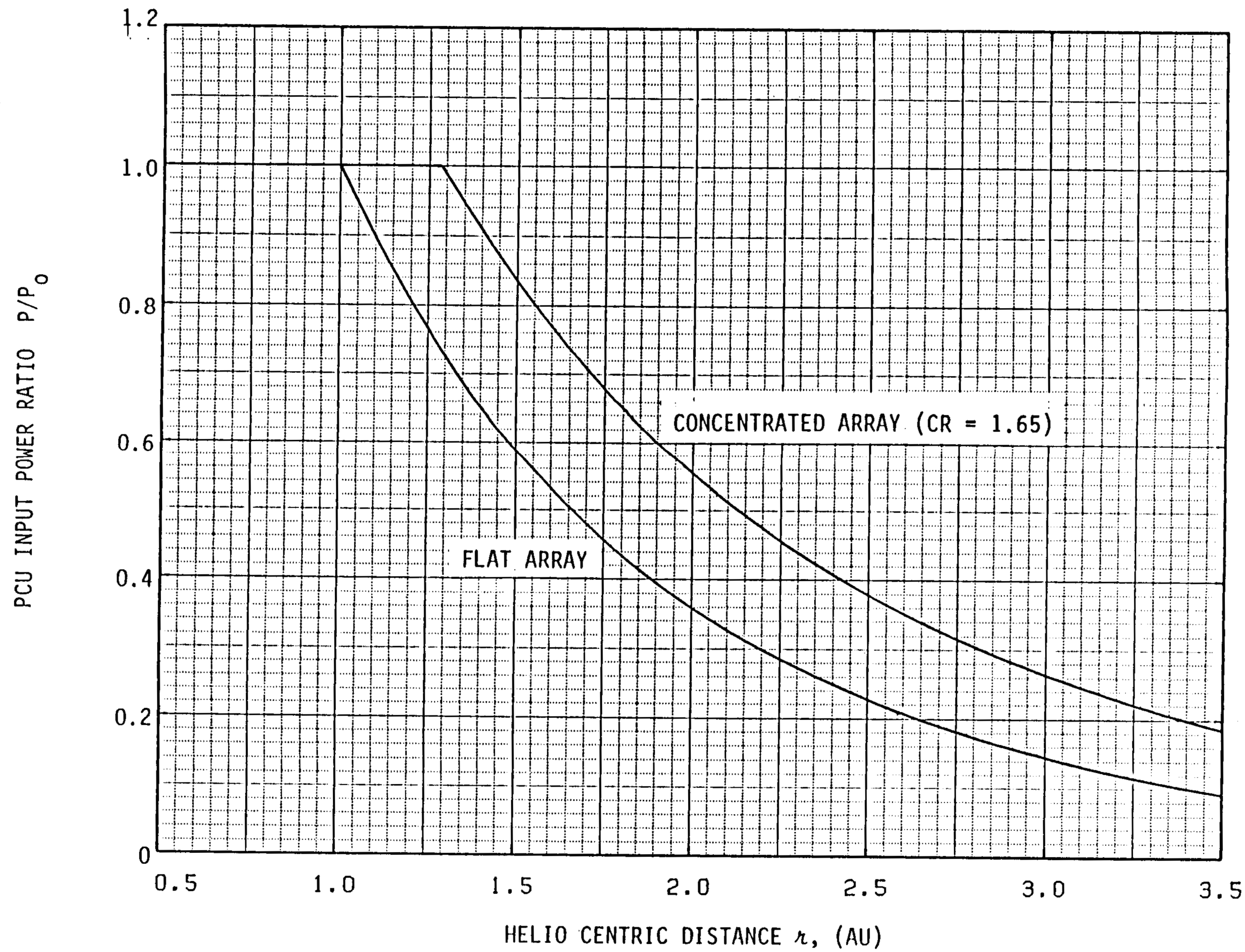


Figure 2-12. NORMALIZED SEP POWER PROFILE

in this report apply mainly to the European SEP system, some comparisons with ASEP performance are shown.

Asteroid and Comet Missions. An assessment was made of the European SEP design requirements and capabilities to perform advanced exploration of asteroids and comets. The study approach involved a parametric analysis of mass delivery performance for five representative mission examples showing the effects of launch vehicle, power level, and flight mode choices. These missions are:

1. Multiple Asteroid Rendezvous
2. Comet Rendezvous
3. Asteroid + Comet Rendezvous
4. Single and Multiple Asteroid Sample Return
5. Comet Nucleus Sample Return.

Launch vehicle/upper stage performance is shown in Figure 2-13 with capability ranging from the Ariane 44L to the Shuttle/Centaur(G').

Multiple Asteroid Rendezvous. The multiple asteroid rendezvous mission example is described in Figures 2-14 through 2-16 and Table 2-25. This rendezvous tour includes five targets beginning with the asteroid Vesta. Launched in 1993, the total flight time to the final target is 8.4 years. A 60-day stay time is specified for each target (90 days for Vesta) and transfer time between targets varies from 385 days to 750 days. This tour is arranged to include asteroids of different material classification (U, S, C, M) and to generally spiral outward through the asteroid belt.

Assuming a nominal spacecraft mass requirement of 700 kg, performance results show that a Shuttle/Centaur launch capability is needed for a flat array SEP design and that the PCU input power needed is about 24 kw. Even with a concentrated array design the Shuttle/TOS capability is very marginal for five targets; however, the Shuttle/Centaur(G) can easily launch this mission with large mass margin for a relatively small power requirement of 16 kw. Table 2-25 is a performance mass statement for this mission and shows that if the number of targets is reduced to three the mission can be captured with the Shuttle/TOS launch and marginally with the Ariane 44L.

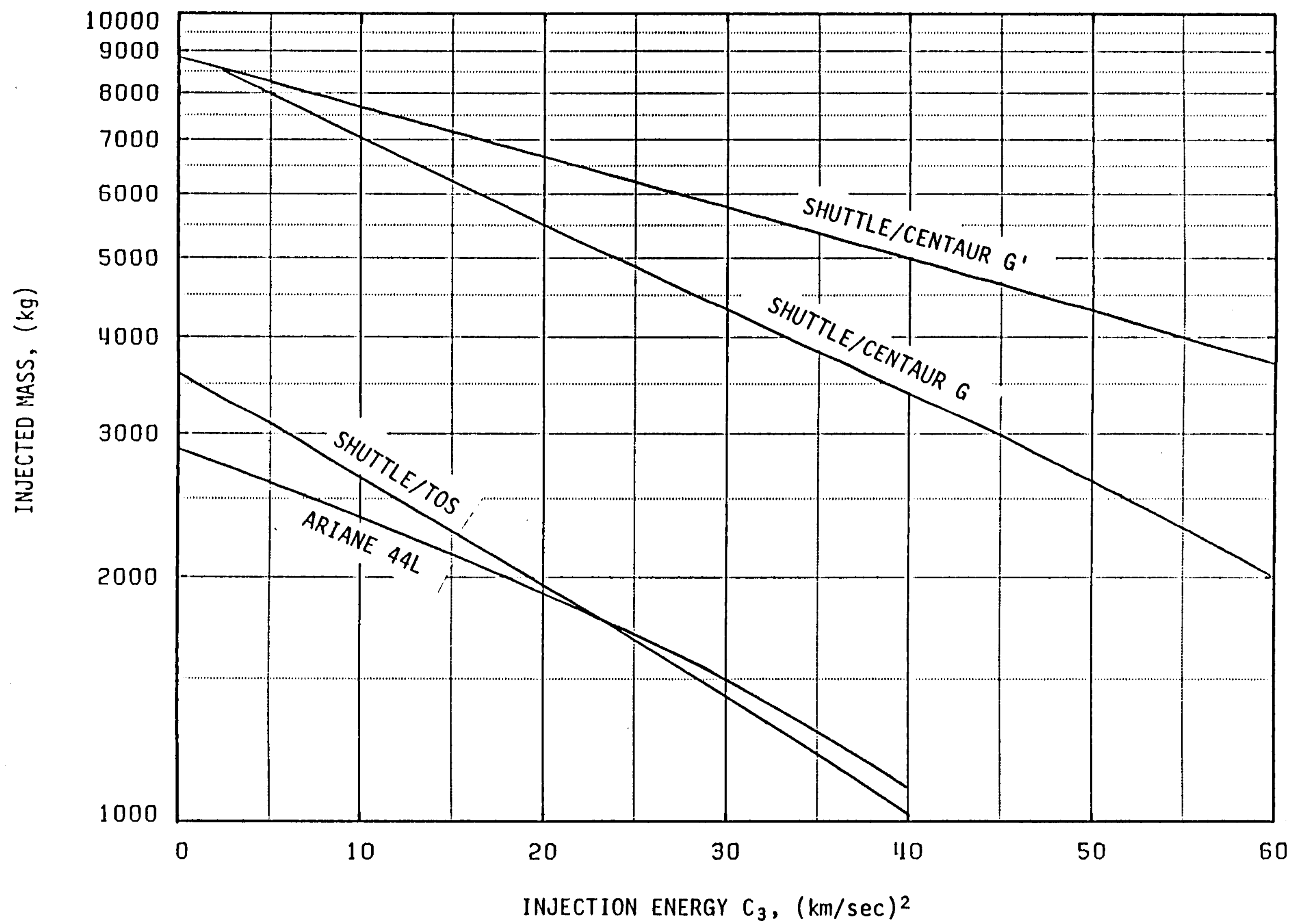
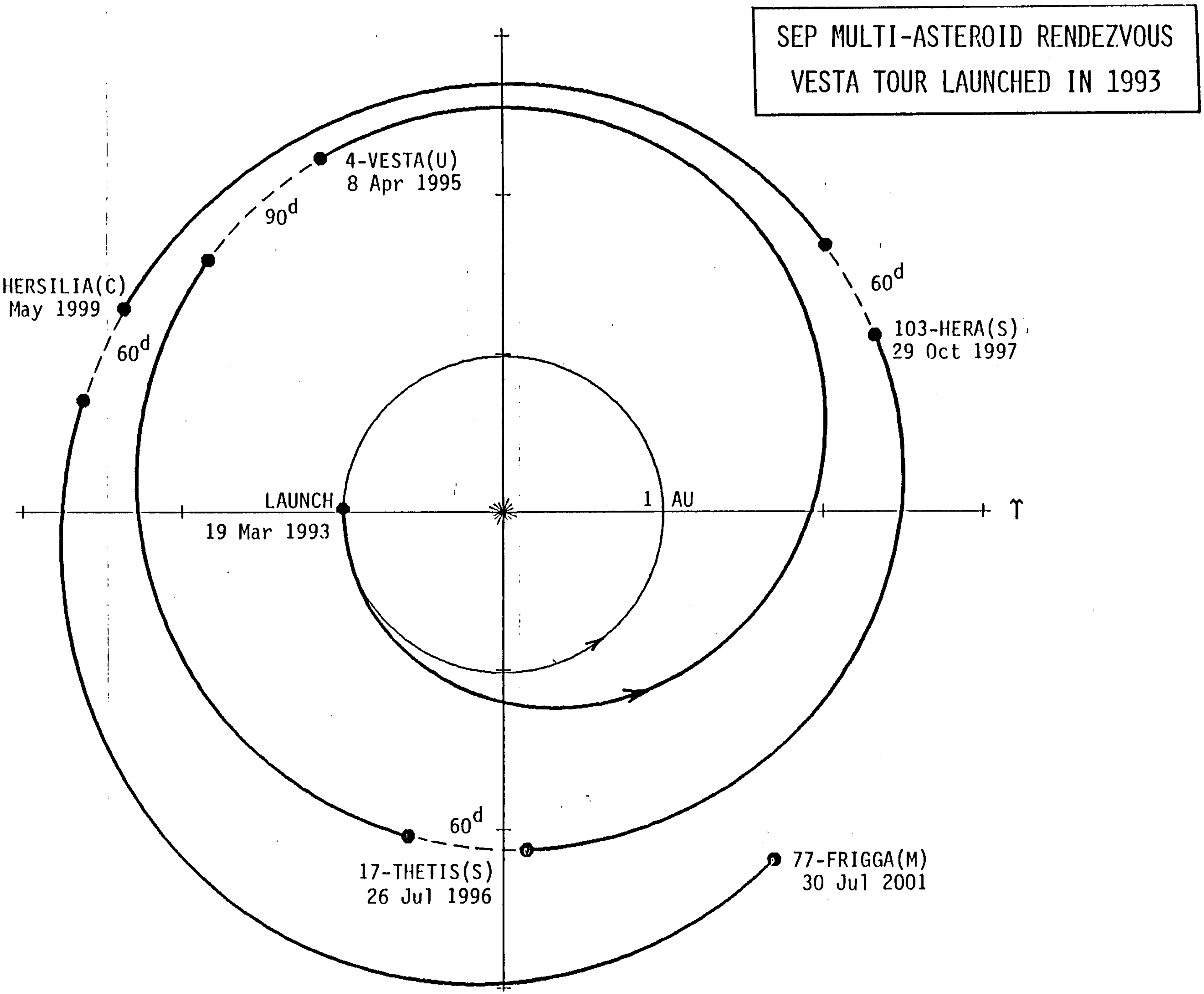


Figure 2-13. LAUNCH VEHICLE PERFORMANCE



SEP MULTI-ASTEROID RENDEZVOUS
VESTA TOUR LAUNCHED IN 1993
4-VESTA(U)
8 Apr 1995
90d
206-HERSILIA(C)
12 May 1999
60d
60d
103-HERA(S)
29 Oct 1997
LAUNCH
19 Mar 1993
1 AU
♈
60d
17-THETIS(S)
26 Jul 1996
77-FRIGGA(M)
30 Jul 2001

Figure 2-14.

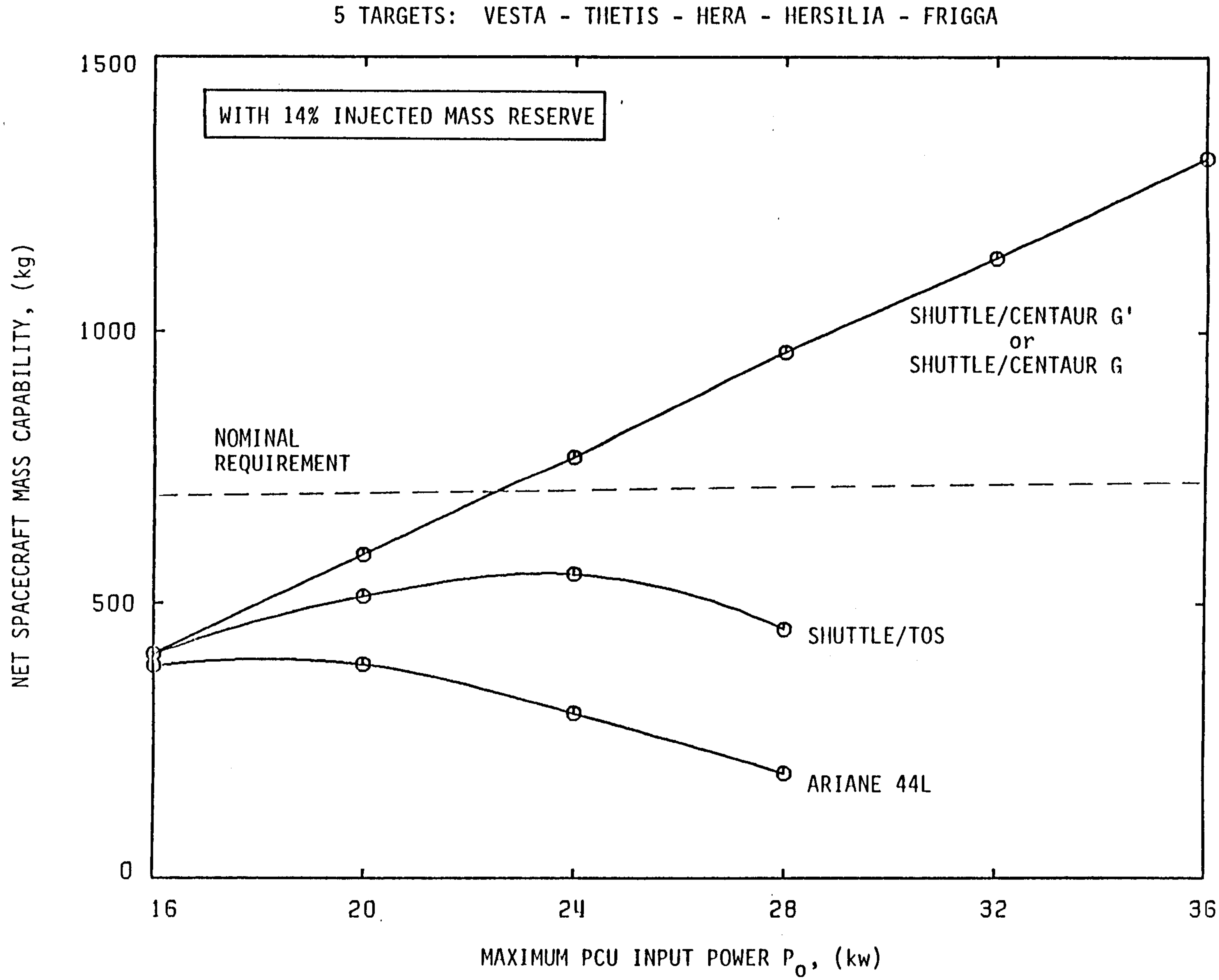


Figure 2-15. SEP (FLAT ARRAY) PERFORMANCE FOR VESTA MULTI-ASTEROID RENDEZVOUS TOUR

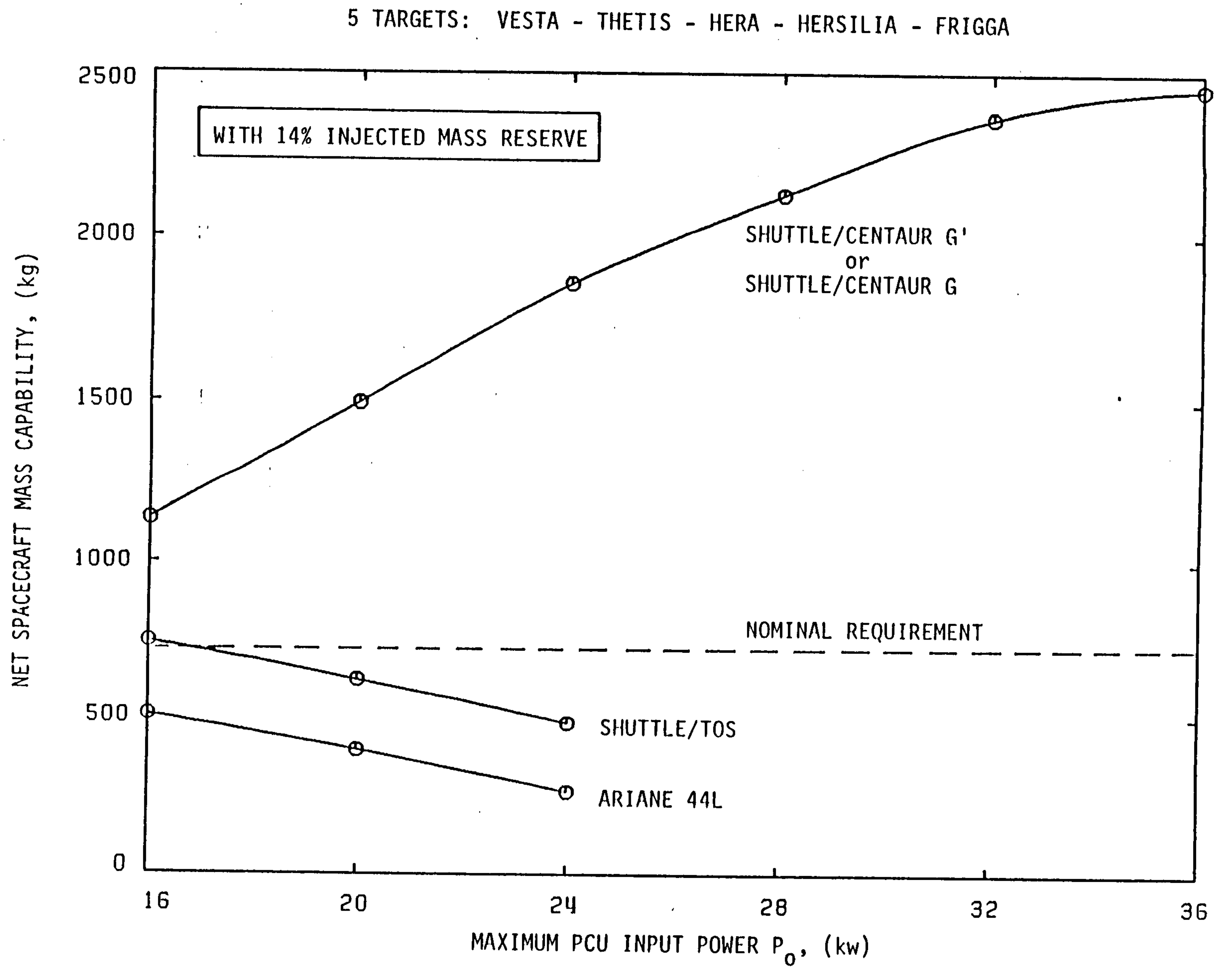


Figure 2-16. SEP (CONCENTRATED ARRAY) PERFORMANCE FOR VESTA MULTI-ASTEROID RENDEZVOUS TOUR

Table 2-25

PERFORMANCE MASS STATEMENT FOR VESTA MULTI-ASTEROID RENDEZVOUS TOUR

	5 TARGETS		(1st) 3 TARGETS	
	FLAT ARRAY P_o = 24 kw	CONC. ARRAY P_o = 16 kw	FLAT ARRAY P_o = 20 kw	CONC. ARRAY P_o = 16 kw
MISSION MODULE	725 kg	725 kg	725 kg	725 kg
SEP SYSTEM DRY MASS	1134	916	998	916
SEP PROPELLANT	1202	1064	785	653
TOTAL INITIAL MASS	3061	2705	2508	2294
PAYLOAD ADAPTER	127	113	104	96
REQUIRED INJECTED MASS	3188	2818	2612	2390
INJECTED MASS MARGINS				
ARIANE 44L (@ C_3 = 4)	—	—	38	260
SHUTTLE/TOS (@ C_3 = 4)	—	371	577	799
SHUTTLE/CENTAUR G (@ C_3 = 25)	1683	2053	2420	2604

Comet Rendezvous. A rendezvous mission to Comet Wild 2 at its apparition in 2002 is illustrated in Figure 2-17. The flight time is 1045 days with arrival occurring 50 days before the comet's perihelion. Performance tradeoff data for this mission are shown in Figures 2-18 and 2-19. As a point of reference, the nominal requirement for net spacecraft mass is taken as 725 kg. Employing a flat array SEP, it is seen that the Shuttle/Centaur readily captures this mission for SEP power levels above 16 kw. At P_0 = 24 kw, the Shuttle/TOS can also perform this mission but the mass margin is only about 100 kg. SEP array concentration is effective for comet rendezvous in terms of larger mass margins or reduced power, and even the Ariane 44L has marginal capability for launching this mission.

Asteroid + Comet Rendezvous. The possibility of combining asteroid and comet rendezvous in one mission is illustrated in Figure 2-20. With a launch in 1997, the asteroid Vesta is encountered after a flight time of 650 days. Close-up investigation of Vesta is made during the 109 day stay time, after which the spacecraft continues on its course for rendezvous with the comet Wild 2 in December, 2002. During this course there is the opportunity to fly by the smaller asteroids Sappho and Boyer. Mission performance is shown in Figure 2-21 where net spacecraft mass capability is plotted against SEP input power. The more capable Shuttle/Centaur launch vehicle is needed for this energetic mission. Assuming a net spacecraft mass requirement of 725 kg, it is seen that a flat array SEP can capture this mission with a power level of 24 kw. Array concentration offers even greater performance margin and a lower power design of about 16 kw. Further details of the trajectory and mass performance profiles are listed in Table 2-26 for the 24-kw flat array SEP. Total mission duration is 5.5 years and total SEP propellant is 1059 kg or about one-third of the injected mass requirement.

Asteroid Sample Return. The SEP trajectory profiles for sample return missions to the asteroid Fortuna (single target) and the double target sequence Fortuna + Anahita are shown in Figures 2-22 and 2-23. Stay time at each target is specified as 60 days. These missions are carried out by the SEP system except for: (1) the sampling phase which employs a separable and reusable lander utilizing chemical propellants; and (2) the final sample

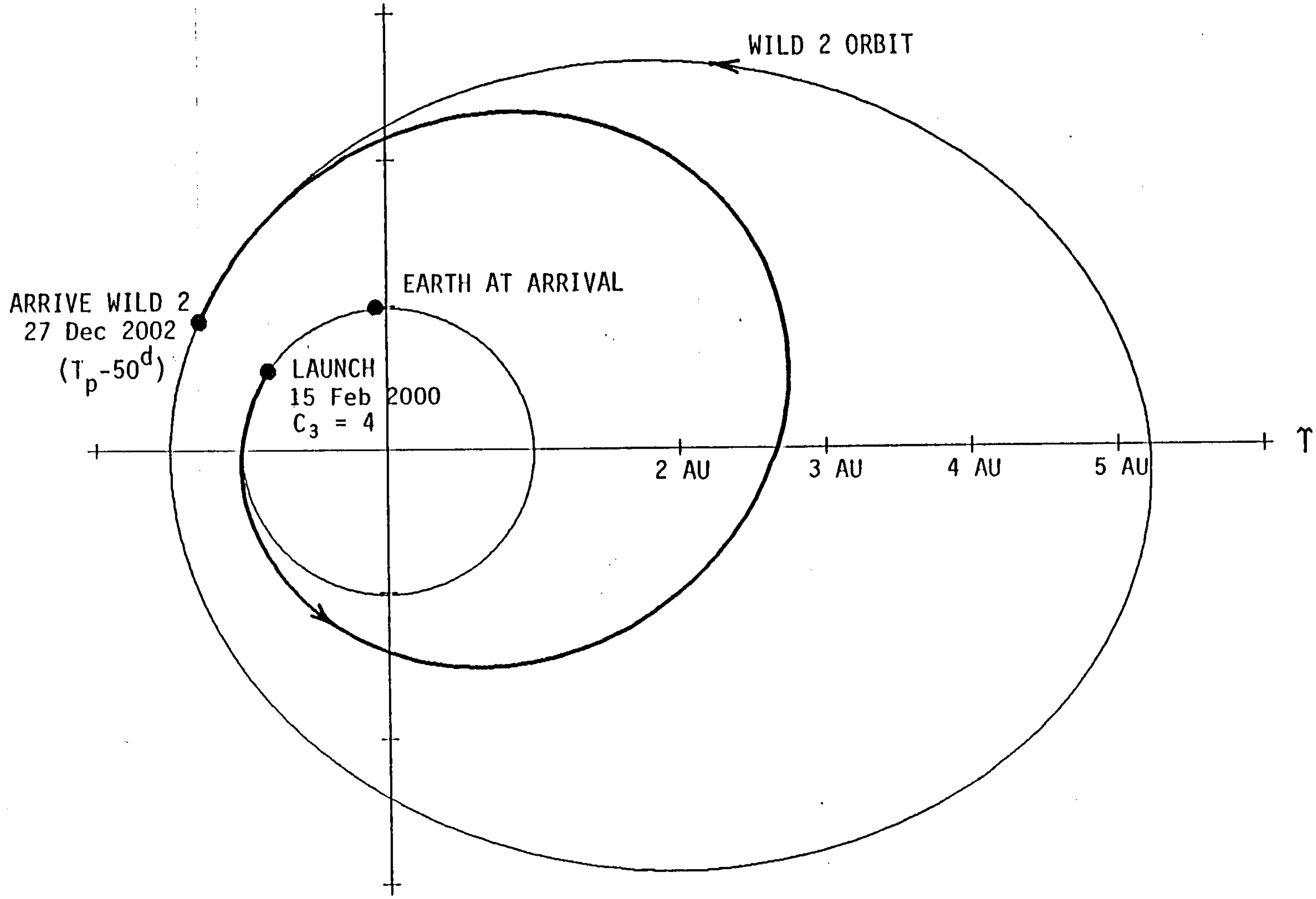


Figure 2-17. COMET WILD 2 RENDEZVOUS MISSION - SEP TRAJECTORY PROFILE

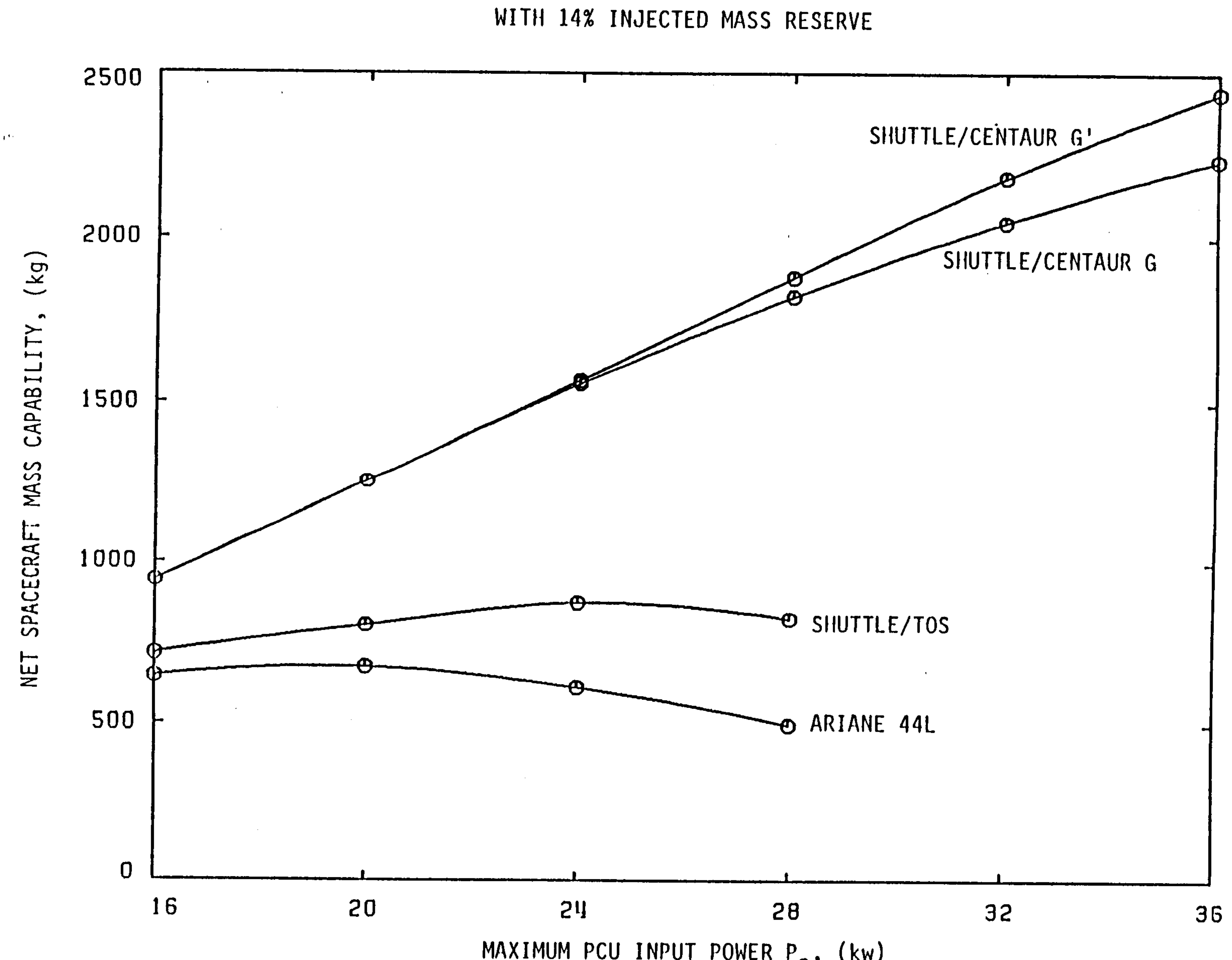


Figure 2-18. SEP (FLAT ARRAY) PERFORMANCE FOR COMET WILD 2 RENDEZVOUS AT T_P-50^d

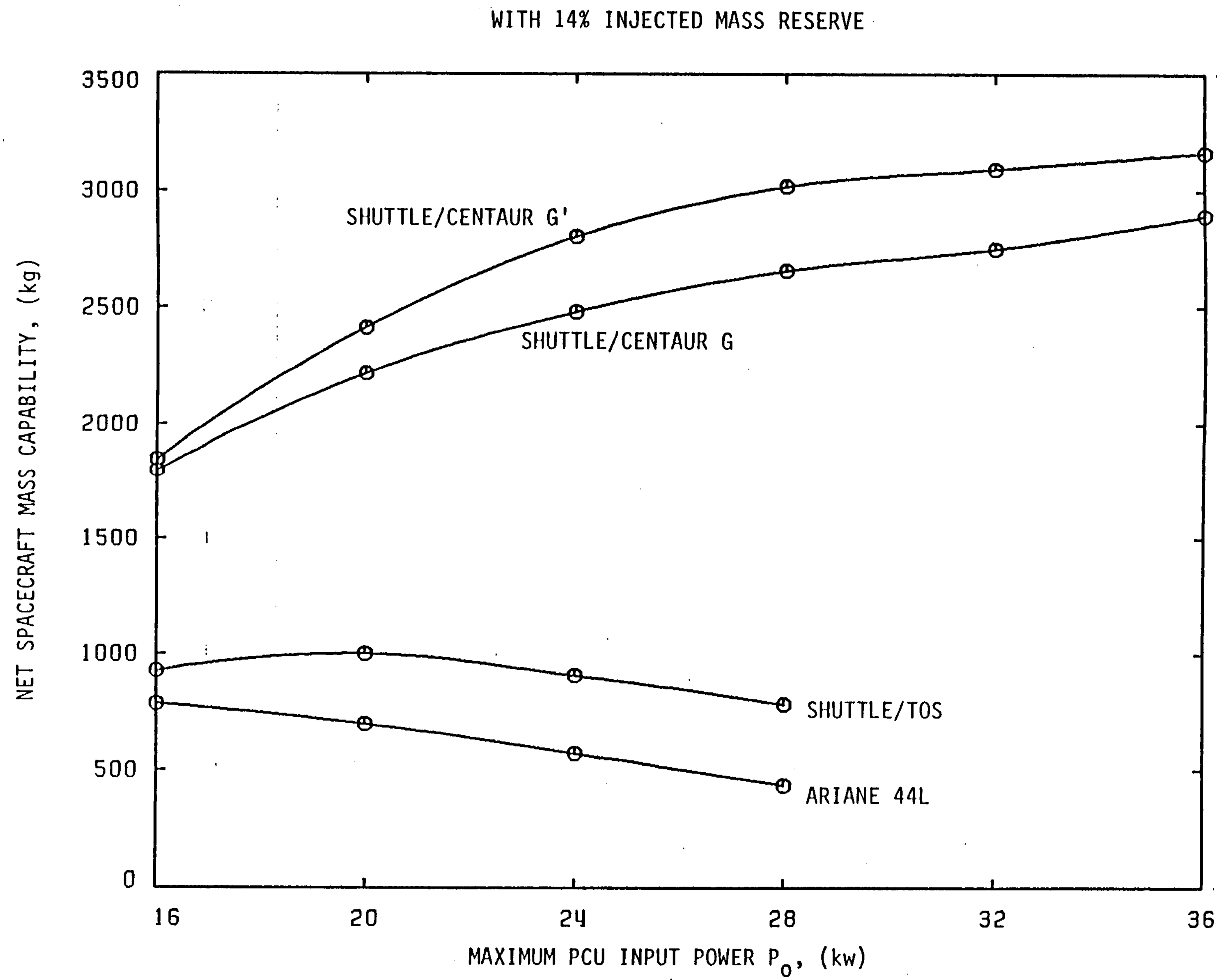


Figure 2-19. SEP (CONCENTRATED ARRAY) PERFORMANCE FOR COMET WILD 2 RENDEZVOUS AT T_p-50^d

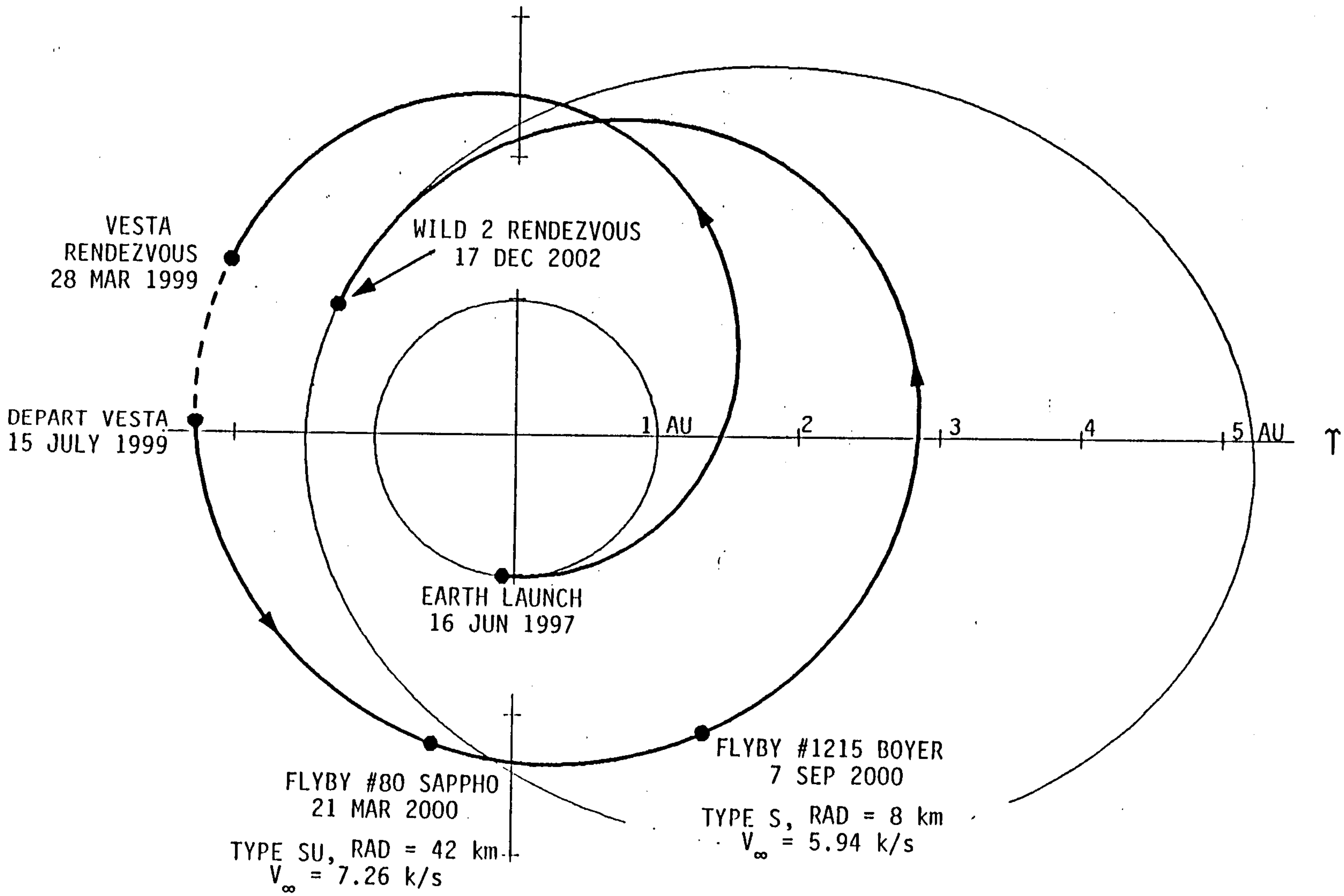


Figure 2-20. VESTA + COMET WILD 2 RENDEZVOUS TOUR - SEP TRAJECTORY PROFILE

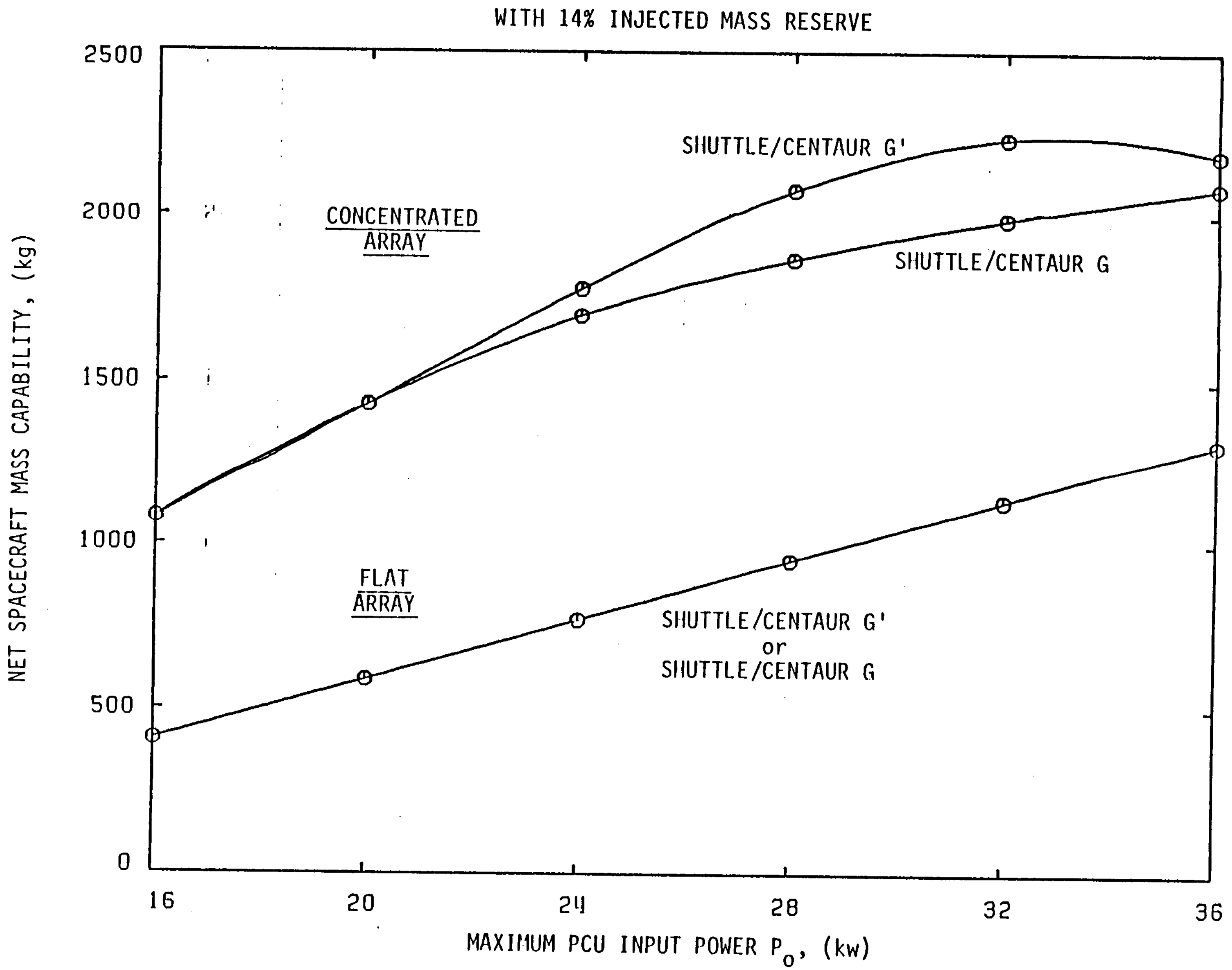


Figure 2-21. SEP PERFORMANCE FOR VESTA + COMET WILD 2 RENDEZVOUS TOUR

Table 2-26

VESTA + COMET WILD 2 RENDEZVOUS TOUR MISSION PROFILE

• DESCRIPTION

Launch Year.........................1997
Number of Targets...................4
SEP Propulsion System...............Flat Array, P_0 = 24 kw

• TRAJECTORY

C_3 (km^2/sec^2).......25.0 Target Stay Time (days)..........109

DLA (deg)...........-26.1 Total Mission Duration (yrs).....5.5

Event	Date	Elapsed Time (days)
Earth Launch	16 Jun 1997	0
Rendezvous with Vesta	28 Mar 1999	650
Depart Vesta	15 Jul 1999	759
Flyby ast. #80 Sappho (2.3 AU)	21 Mar 2000	1009
Flyby ast. #1215 Boyer (2.5 AU)	7 Sep 2000	1179
Rendezvous with Comet Wild 2 (T_p-50^d)	17 Dec 2002	2019

• MASS PERFORMANCE

Mission Module................................ 725 kg
SEP System Dry Mass...........................1134

Mass at Wild 2 Rendezvous.....................1859
SEP Propellant Boyer to Wild 2................ 427

Mass at Boyer Flyby...........................2286
SEP Propellant Sappho to Boyer................ 33

Mass at Sappho Flyby..........................2319
SEP Propellant Vesta to Sappho................ 98

Mass at Vesta Departure.......................2417
Stationkeeping................................ 50
Mass at Vesta Rendezvous......................2467
SEP Propellant Earth to Vesta................. 501

Initial Mass Departing Earth..................2968
Payload Adapter............................... 124

Required Injected Mass........................3092

Injected Mass Capability....Shuttle/Cent(G') = 6205 /Cent(G) = 4871
Injected Mass Margin........Shuttle/Cent(G') = 3113 /Cent(G) = 1779

$\sum$ SEPS propellant = 1059 kg

Figure 2-22. FORTUNA SAMPLE RETURN MISSION -- SEP TRAJECTORY PROFILE

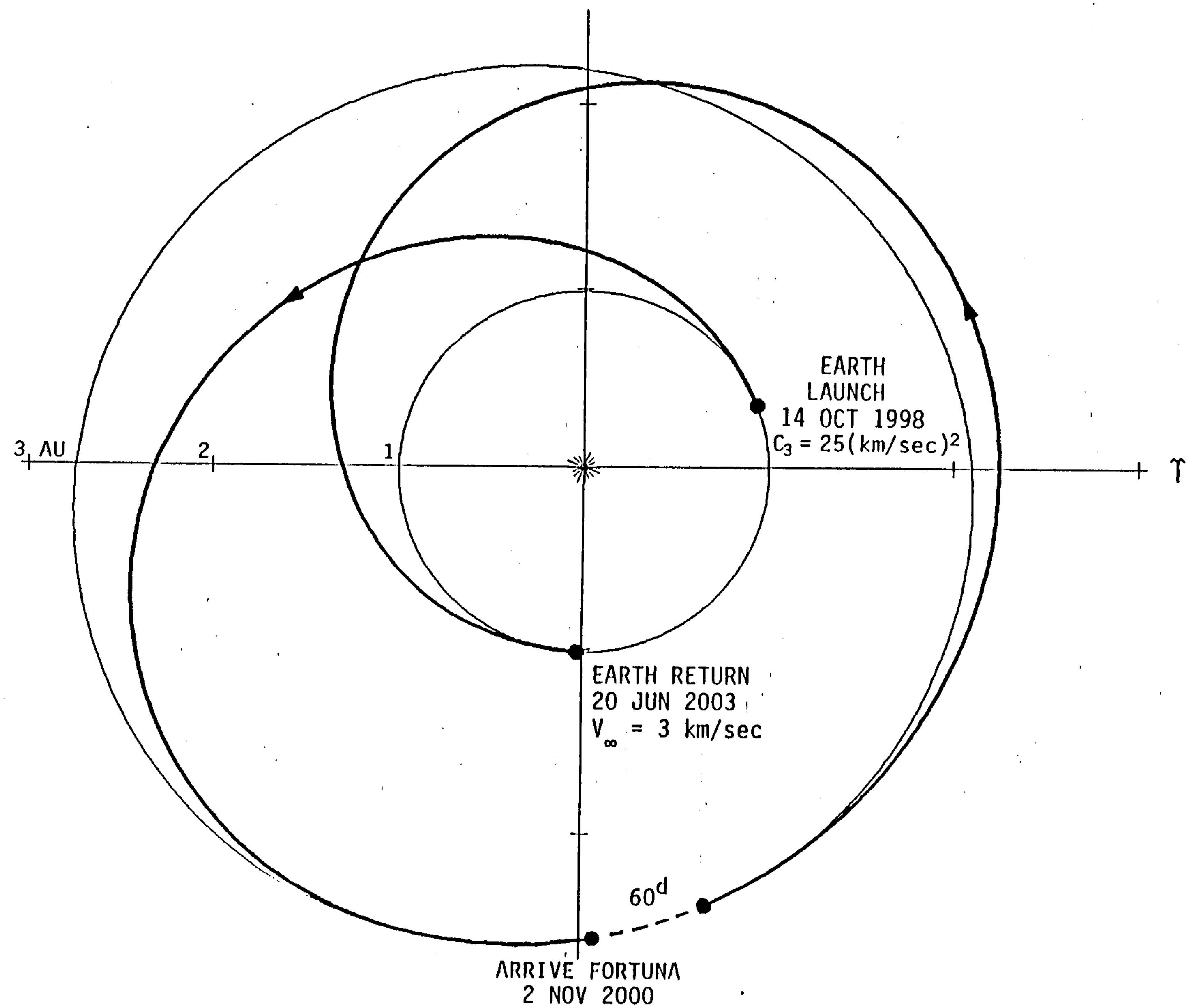
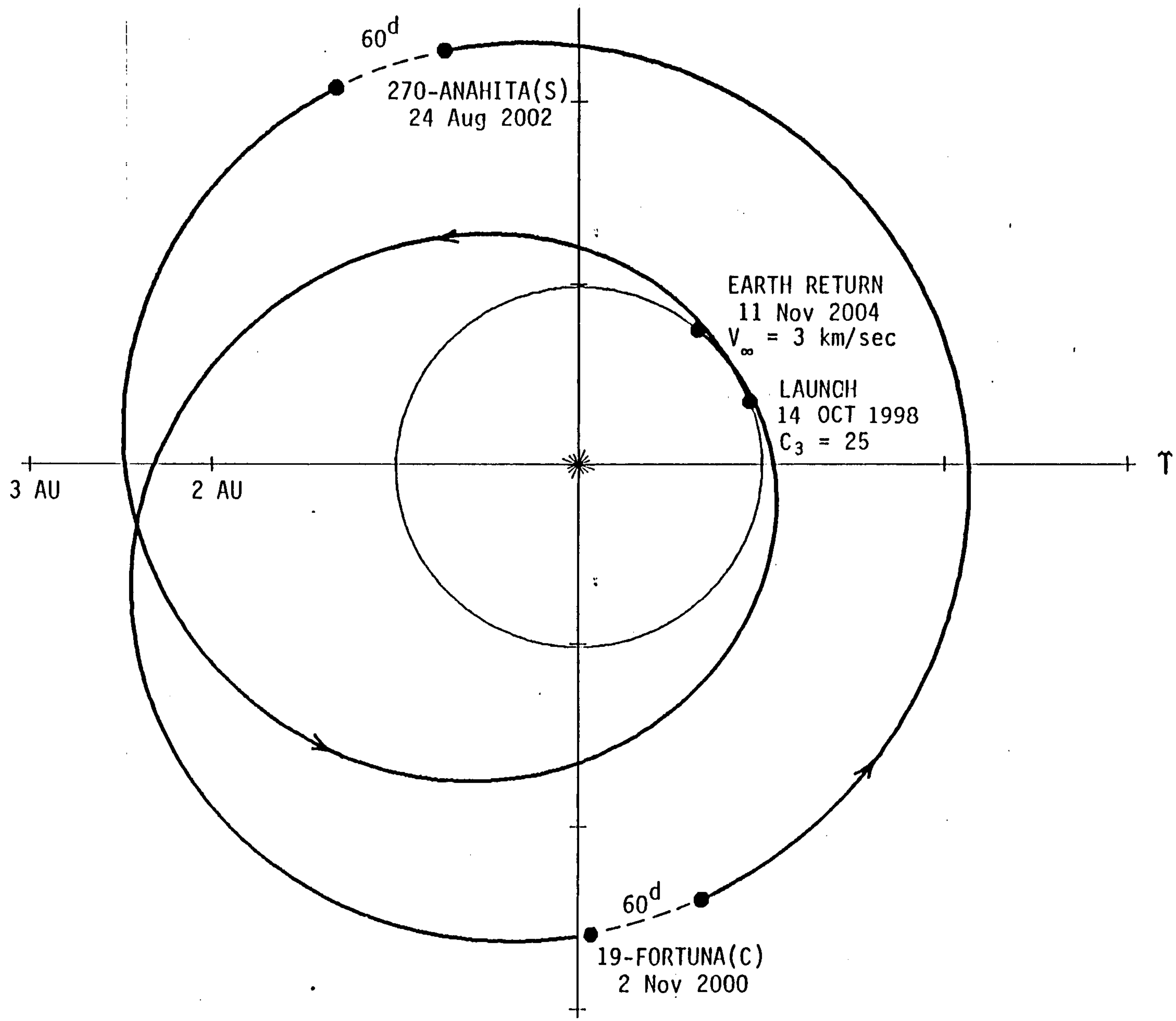


Figure 2-23. FORTUNA + ANAHITA SAMPLE RETURN MISSION - SEP TRAJECTORY PROFILE



return phase which employs a solid rocket to insert the sample capsule into a 200 n. mile circular orbit at Earth. Figure 2-24 is a bar chart of performance requirements and shows that a Shuttle/Centaur(G) launch capability is needed (but with substantial margin) in combination with either a 24-kw flat array SEP or a 16-kw concentrated array SEP. Note that the addition of Anahita sample return costs very little from a performance standpoint, the reason being that the Fortuna-Anahita leg and the Anahita-Earth leg is just slightly more energetic (i.e., propellant usage) than the Fortuna-Earth leg. Details of the trajectory and mass performance profiles are listed in Tables 2-27 and 2-28 assuming use of a 24-kw flat array SEP system.

Comet Nucleus Sample Return. Two mission modes were examined regarding the return to Earth of a small core sample from the nucleus of Comet Wild 2. The first of these obtains the sample in the vicinity of aphelion when the comet is in a near-quiescent state. The launch is in 1995 and a hybrid SEP/chemical flight system is employed, i.e., the SEP is used only during the first part of the mission and is jettisoned prior to comet rendezvous. The second mission mode obtains the sample in the vicinity of perihelion. In this case the launch occurs in 1999 and the SEP system is used throughout the mission except for surface sampling operations (a separable lander) and Earth orbit capture of the sample capsule (solid rocket or aerocapture). Figures 2-25 and 2-26 show the trajectory plots for these two mission modes.

The aphelion mission can be performed with a Shuttle/Centaur(G) launch, a 28-kw flat array SEP system, space-storable retropropulsion, and an aerocapture return system. Table 2-29 lists the trajectory and mass data. The large injected mass margin would probably allow use of an Earth-storable retropropulsion system. The perihelion mission can be performed optionally by either a 36-kw flat array SEP with aerocapture return, or a 20-kw concentrated array SEP with solid rocket capture. Table 2-30 describes the latter mission profile.

Summary of Results. Performance data for the five primitive body mission applications are summarized by the comparative formats of Figure 2-27 and Table 2-31. Ariane and Shuttle/TOS launch vehicles have limited capability

Figure 2-24. ASTEROID SAMPLE RETURN

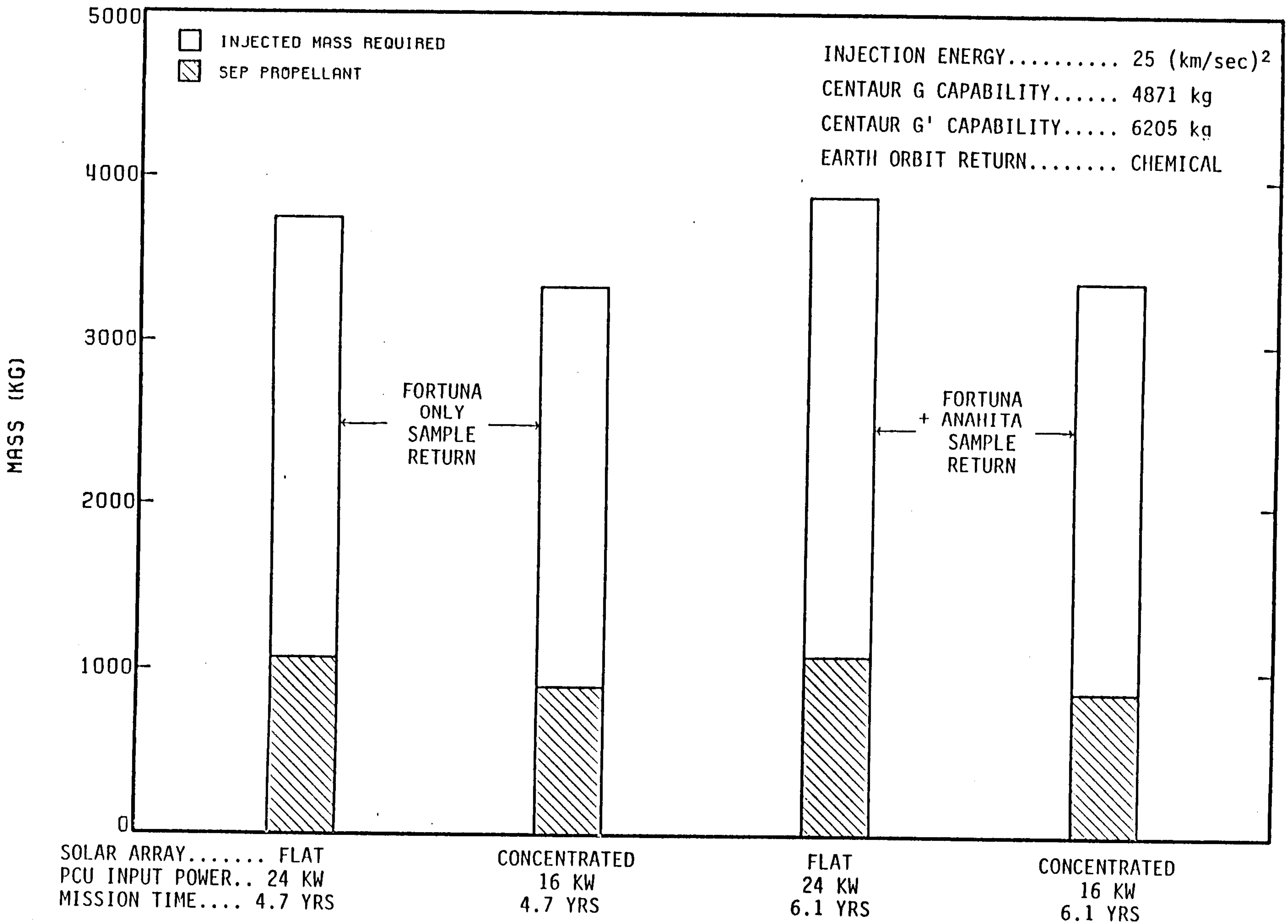


Table 2-27

FORTUNA SAMPLE RETURN MISSION PROFILE

- **DESCRIPTION**

Launch Year........................1998
Number of Targets..................1 (Fortuna)
SEP Propulsion System..............Flat Array, P_0 = 24 kw
Earth Return.......................Solid Rocket Capture

- **TRAJECTORY**

C_3 (km^2/sec^2).......25.0   Target Stay Time (days)..........60

DLA (deg)...........16.7   Total Mission Duration (yrs).....4.7

Event	Date	Elapsed Time (days)
Earth Launch	14 Oct 1998	0
Arrive Fortuna	2 Nov 2000	750
Earth Return (V_∞ = 3 km/sec)	20 Jun 2003	1710

- **MASS PERFORMANCE** Shuttle/Centaur (G)

Mission Module................................	720(1)	kg
Chemical Stationkeeping and RCS Propellant.....	125	
Sampling System...............................	250	
Sample Capsule................................	50	(2)
EOC Solid Rocket..............................	221	(2)
SEP System Dry Mass...........................	1134	(3)
SEP Propellant................................	1071	(3)
Total Initial Mass............................	3571	
Payload Adapter...............................	149	
Injected Mass Required........................	3720	
Injected Mass Capability......................	4871	
Injected Mass Margin..........................	1151	

(1) Mission Module jettisoned in part at Anahita and Earth

(2) Assume Earth Orbit Capture upon return --- 200 n.mi. circular

(3) SEPS Propellant Usage: Earth → Fortuna 559 kg
Anahita → Earth 512 kg

Table 2-28

MULTIPLE ASTEROID SAMPLE RETURN MISSION PROFILE

- **DESCRIPTION**

Launch Year	1998
Number of Targets	2 (Fortuna + Anahita)
SEP Propulsion System	Flat Array, P_0 = 24 kw
Earth Return	Solid Rocket Capture

- **TRAJECTORY**

C_3 (km^2/sec^2)	25.0
DLA (deg)	16.7
Target Stay Time (days)	60
Total Mission Duration (yrs)	6.1

Event	Date	Elapsed Time (days)
Earth Launch	14 Oct 1998	0
Arrive Fortuna	2 Nov 2000	750
Arrive Anahita	24 Aug 2002	1410
Earth Return (V_∞ = 3 km/sec)	11 Nov 2004	2220

- **MASS PERFORMANCE** Shuttle/Centaur (G)

Mission Module	720(1) kg
Chemical Stationkeeping and RCS Propellant	203
Sampling System	250
Sample Capsule	50
EOC Solid Rocket	221(2)
SEP System Dry Mass	1134
SEP Propellant	1057(3)
Total Initial Mass	3635
Payload Adapter	151
Injected Mass Required	3786
Injected Mass Capability	4871
Injected Mass Margin	1085

(1) Mission Module jettisoned in part at Anahita and Earth

(2) Assume Earth Orbit Capture upon return --- 200 n.mi. circular

(3) SEPS Propellant Usage:

Earth	→ Fortuna	576 kg
Fortuna	→ Anahita	138 kg
Anahita	→ Earth	343 kg

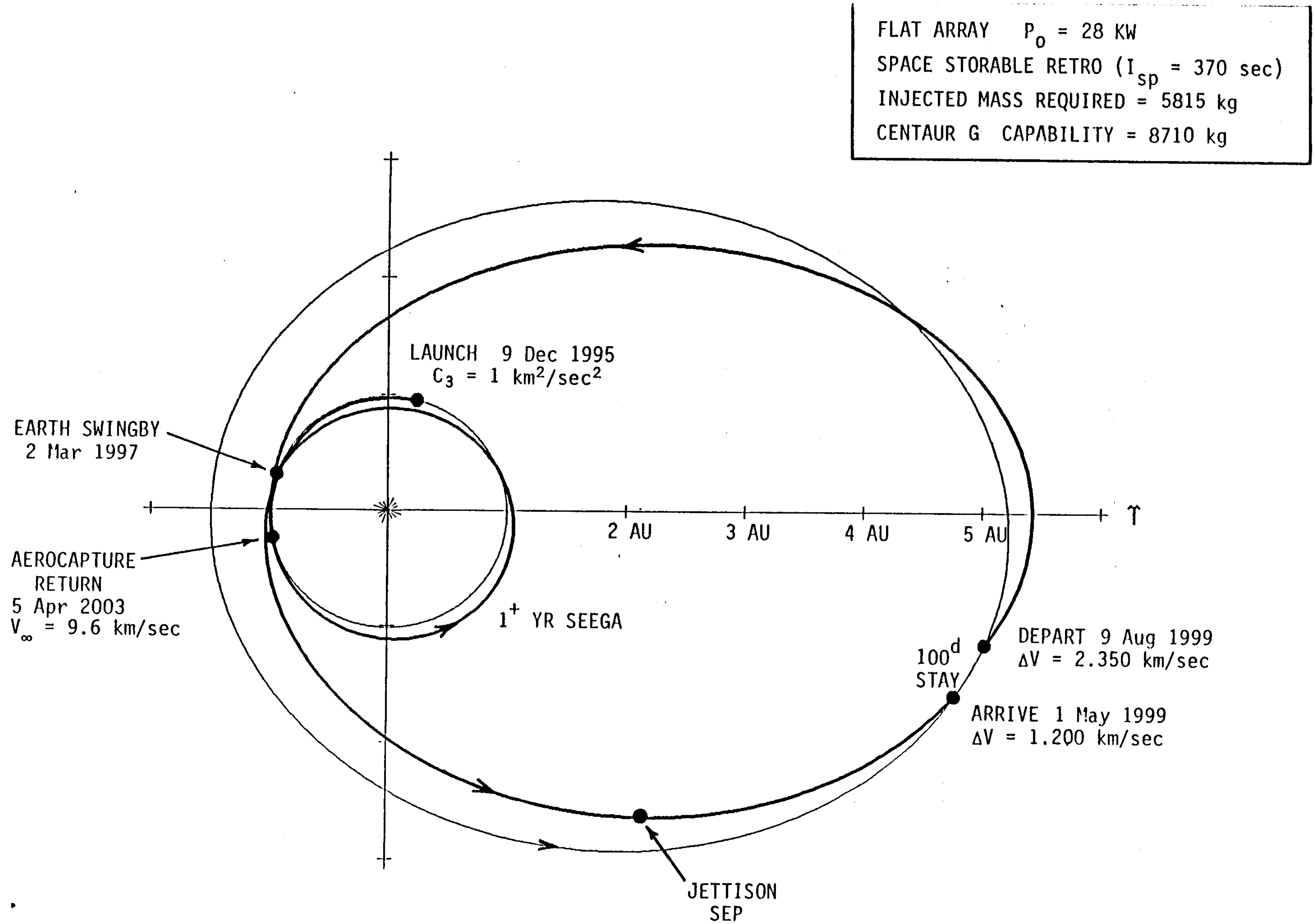


Figure 2-25. COMET WILD 2 SAMPLE RETURN (APHELION MODE) - SEP/CHEMICAL TRAJECTORY PROFILE

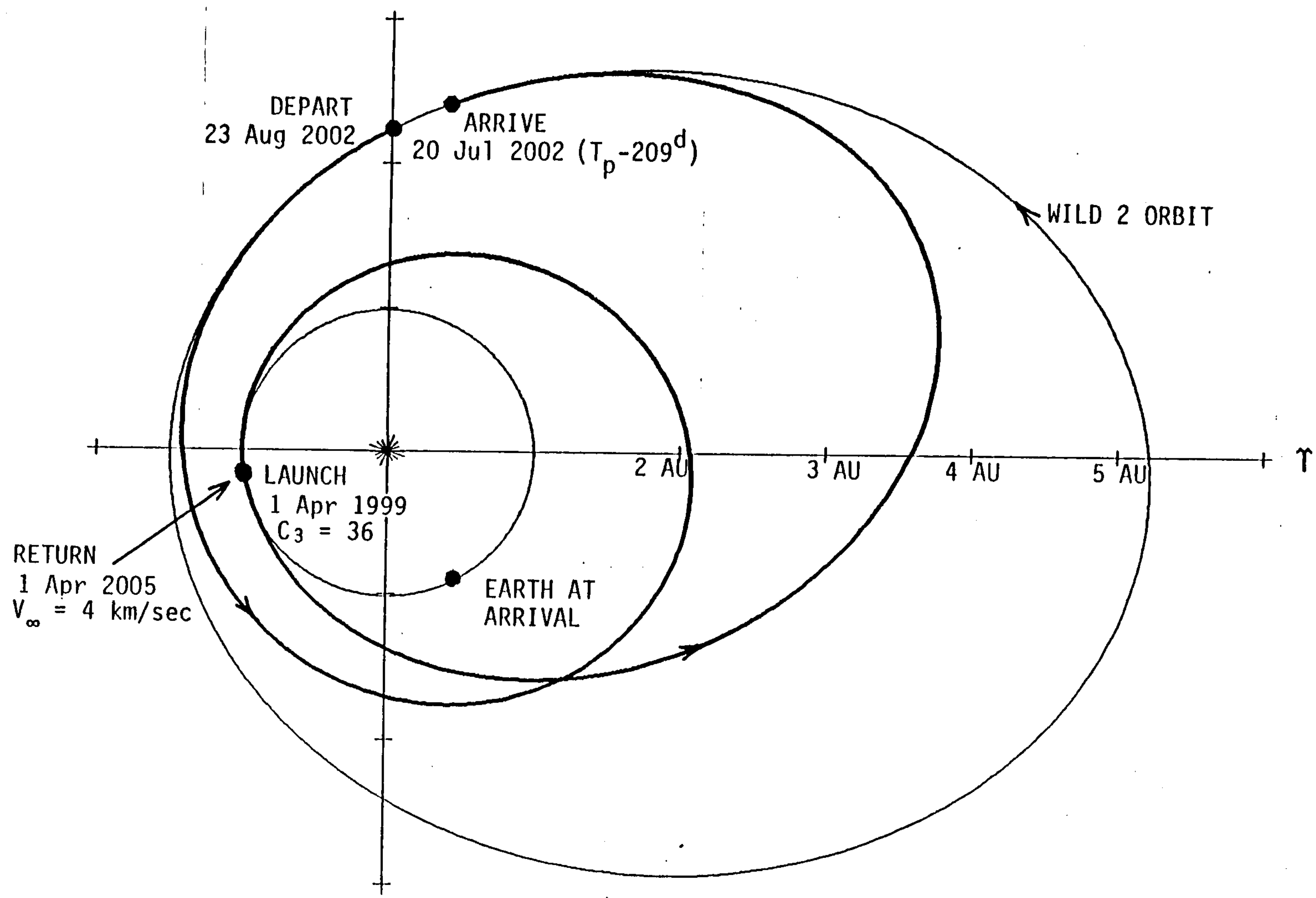


Figure 2-26. COMET WILD 2 SAMPLE RETURN (PRE-PERIHELION MODE) - SEP TRAJECTORY PROFILE

Table 2-29

COMET WILD 2 SAMPLE RETURN MISSION PROFILE

• DESCRIPTION

Target/Apparition....................WILD 2/2003
Perihelion Date......................15 Feb 2003
Launch Year..........................1995
Mission Mode.........................SEEGA with Aphelion Sampling
SEP Propulsion System................Flat Array, P_0 = 28 kw
Retropropulsion System...............Space Storable
Earth Return.........................Aerocapture

• TRAJECTORY

C_3 (km^2/sec^2).......1.0 — Target Stay Time (days)..........100

DLA (deg)...........-21.2 — Total Mission Duration (yrs).....7.3

Event	Date	Elapsed Time (days)
Earth Launch	09 Dec 1995	0
Earth Swingby	02 Mar 1997	450
Jettison SEP (3.4 AU)	14 Mar 1998	827
Arrive Wild 2 (5.0 AU)	01 May 1999	1240
Depart Wild 2	09 Aug 1999	1340
Return Earth (V_∞ = 9.6 km/s)	05 Apr 2003	2674

• MASS PERFORMANCE Shuttle/Centaur (G)

Mission Module................................ 720(1) kg
Aerocapture Return System..................... 40
Sample Capsule................................ 50
Impact Samplers............................... 50
Chemical Propulsion System....................2175(2)

SEP System Dry Mass...........................1271
SEP Propellant................................1276(3)

Total Initial Mass............................5582
Payload Adapter............................... 233

Injected Mass Required........................5815

Injected Mass Capability......................8710
Injected Mass Margin..........................2895

(1) Mission Module jettisoned in part at Wild 2 and Earth

(2) Space Storable propellant usage:

Rendezvous	855 kg
Stationkeeping and RCS	116 kg
Depart	846 kg
	(M_{INERTS} = 358 kg)

(3) SEP Propellant Usage:

Earth → Earth	920 kg
Earth → SEP Jettison	356 kg

Table 2-30

COMET WILD 2 SAMPLE RETURN MISSION PROFILE

- **DESCRIPTION**

Target/Apparition	WILD 2/2003
Perihelion Date	15 Feb 2003
Launch Year	1999
Mission Mode	Pre-perihelion sampling
SEP Propulsion System	Conc. Array, P_0 = 20 kw
Earth Return	Solid Rocket Capture

- **TRAJECTORY**

C_3 (km^2/sec^2).......36.0 Target Stay Time (days)..........34

DLA (deg)...........-20.1 Total Mission Duration (yrs).....6.0

Event	Date	Elapsed Time (days)
Earth Launch	01 Apr 1999	0
Arrive Wild 2 (T -209^d)	20 Jul 2002	1206
Depart Wild 2 (T -175^d)	23 Aug 2002	1240
Earth Return (V_∞ = 4 km/sec)	01 Apr 2005	2190

- **MASS PERFORMANCE** Shuttle/Centaur (G)

Mission Module	720 (1) kg
Chemical Stationkeeping and RCS Propellant	113
Impact Samplers	50
Sample Capsule	50
EOC Solid Rocket	269 (2)
SEP System Dry Mass	1066
SEP Propellant	988 (3)
Total Initial Mass	3256
Payload Adapter	136
Injected Mass Required	3392
Injected Mass Capability	3734
Injected Mass Margin	342

(1) Mission Module jettisoned in part at Wild 2 and Earth approach

(2) Assume Earth Orbit Capture upon return --- 200 n.mi. circular

(3) SEPS Propellant Usage: Earth → Wild 2 703 kg; Wild 2 → Earth 285 kg

Figure 2-27. MASS REQUIREMENTS SUMMARY

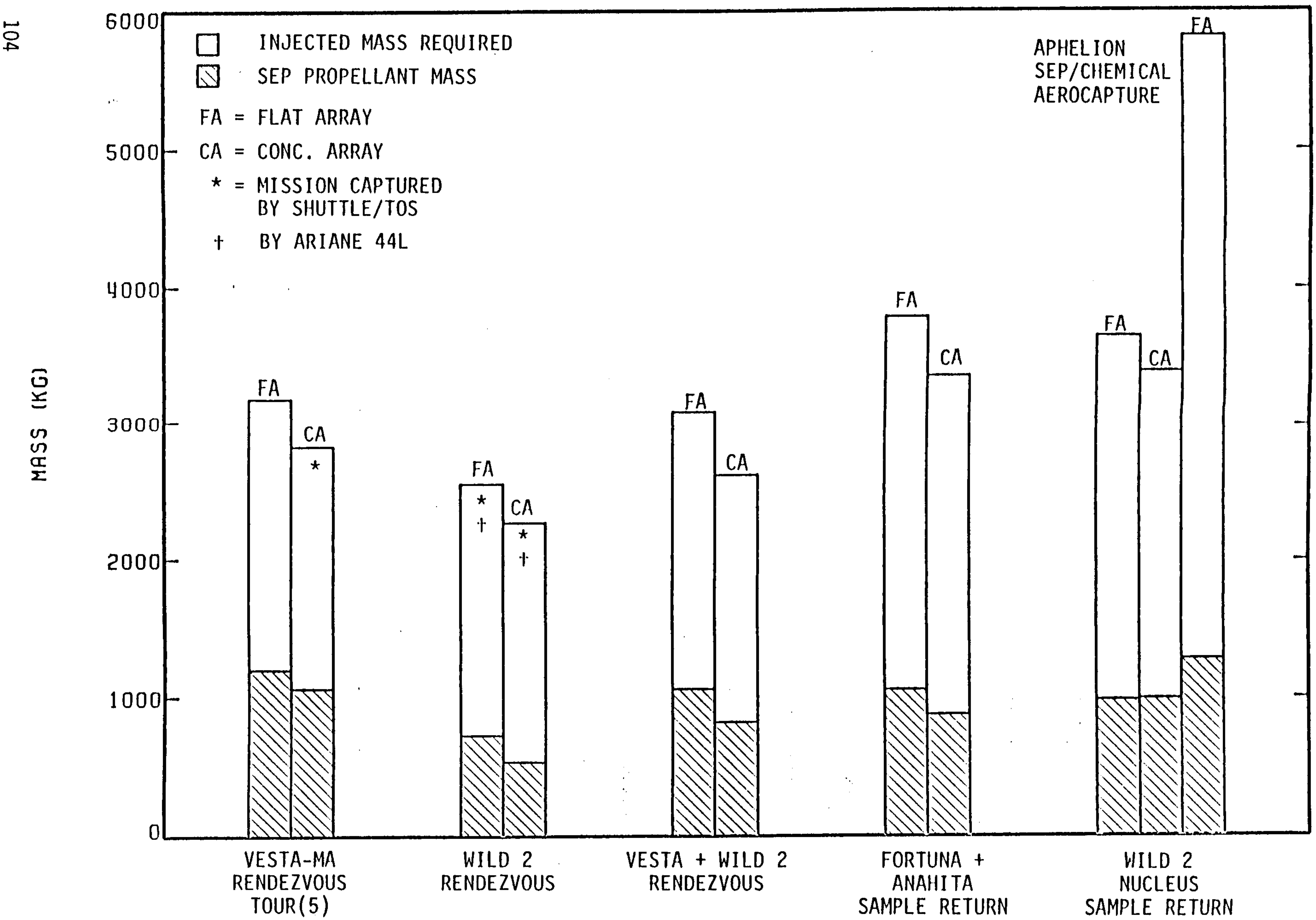


Table 2-31

PRIMITIVE BODY MISSION CAPTURE - MINIMUM SEP POWER REQUIREMENTS (KW)

EXAMPLE OF MISSION TYPE	FLAT ARRAY			CONCENTRATED ARRAY		
	ARIANE	TOS	CENTAUR	ARIANE	TOS	CENTAUR
MULTIPLE ASTEROID RENDEZVOUS (5)	—	—	24	—	16	16
(3)	20	20		16		
COMET RENDEZVOUS	(20)	20	16	16	16	16
ASTEROID + COMET RENDEZVOUS	—	—	24	—	—	16
ASTEROID SAMPLE RETURN	—	—	24	—	—	16
COMET NUCLEUS SAMPLE RETURN (P)	—	—	36 (AC)	—	—	20
SEP/CHEMICAL HYBRID (A)	—	—	28 (AC)	—	—	N/A

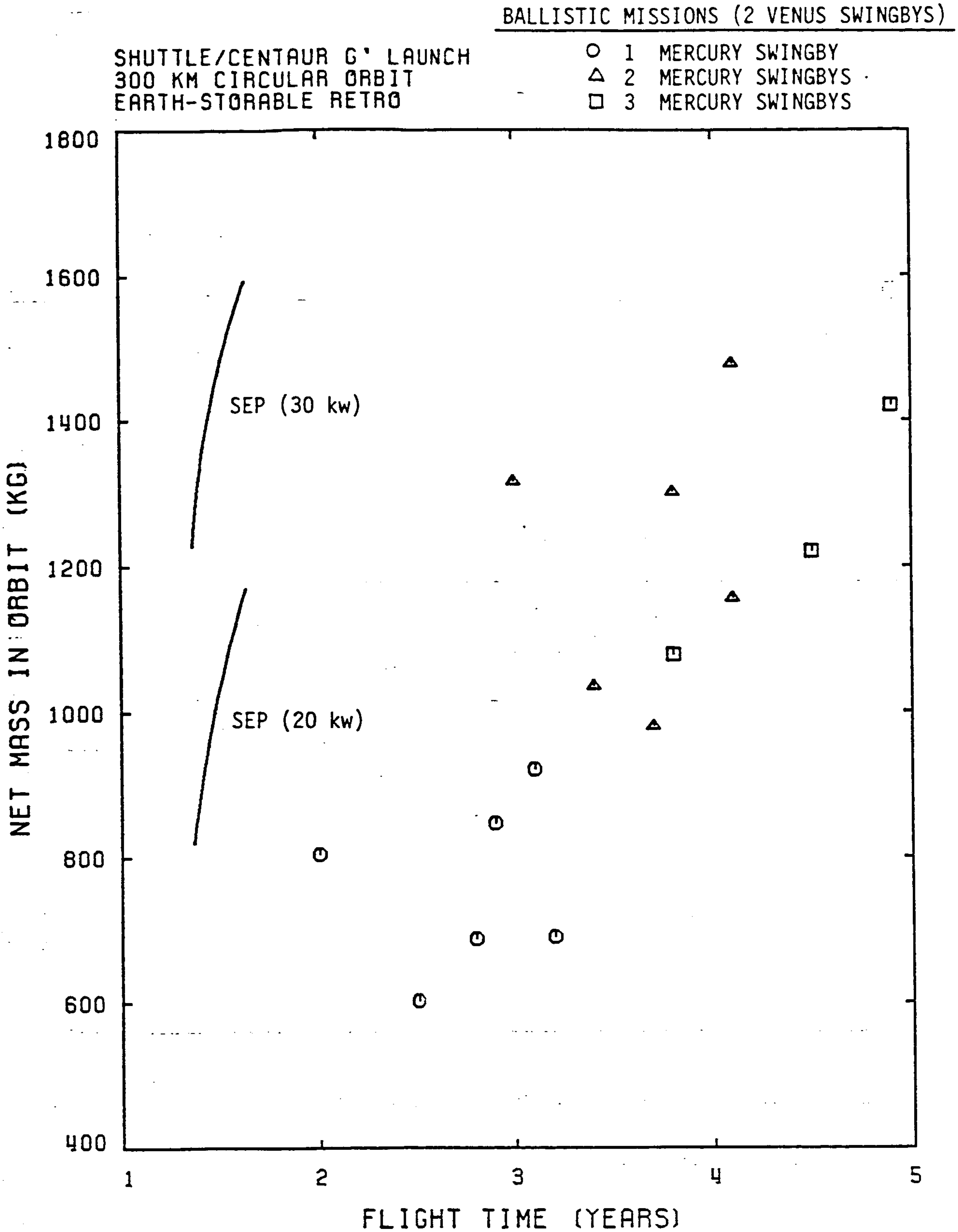
CONCLUSIONS: ARIANE & TOS HAVE LIMITED CAPABILITY; SOME MULTI-ASTEROID AND COMET RENDEZVOUS

WITH CENTAUR, MOST MISSIONS OF INTEREST CAN BE CAPTURED BY A 28 KW FLAT ARRAY DESIGN OR A 20 KW CONCENTRATED ARRAY

for these generally difficult missions; some multi-asteroid rendezvous and comet rendezvous examples are marginally possible. With the Shuttle/Centaur(G) or (G'), most missions of interest can be captured by a flat array SEP with P_0 = 28 kw or by a concentrated array system with P_0 = 20 kw.

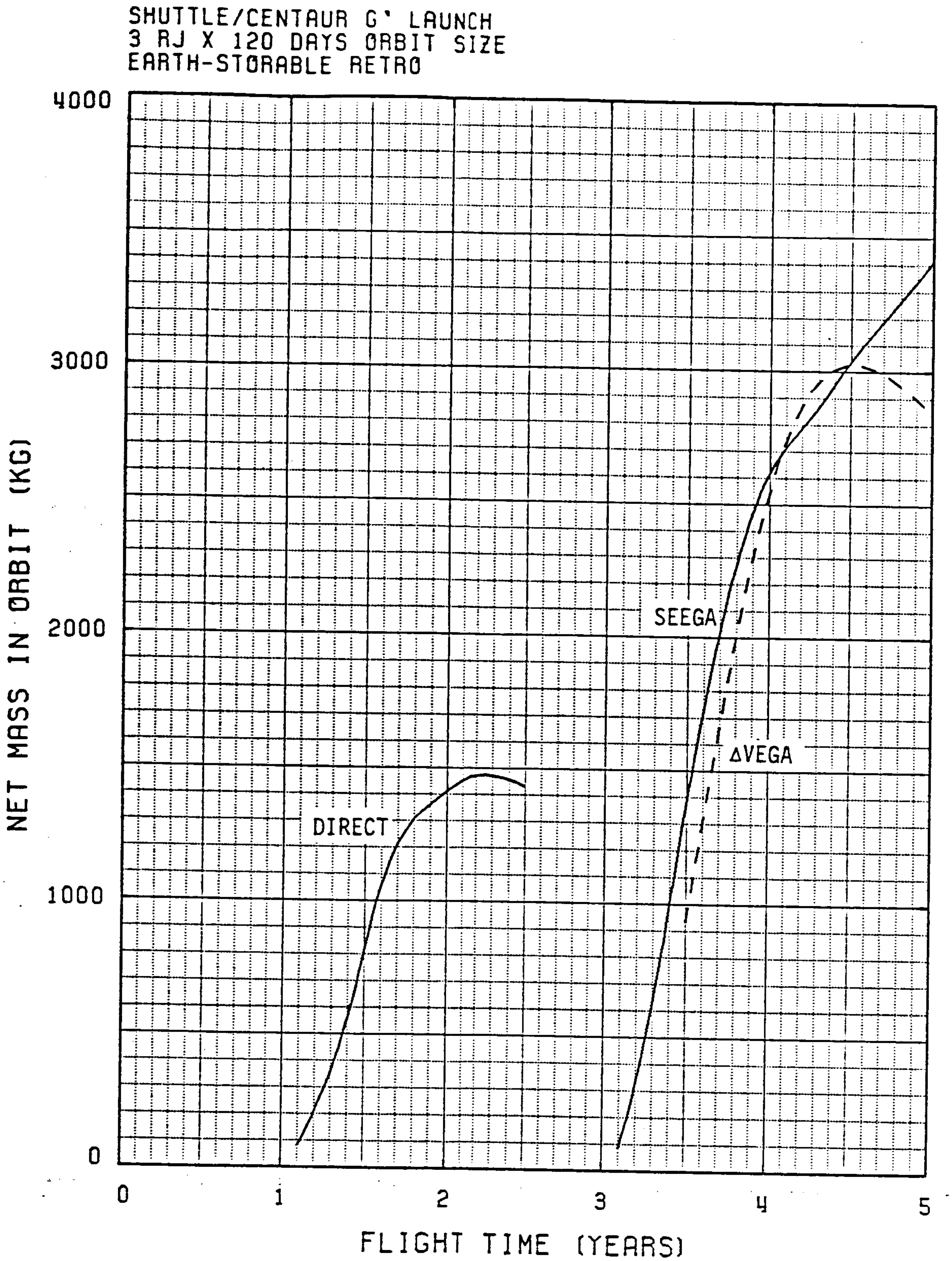
Mercury Orbiter Mission. The objective of this mission is to place a spacecraft into a 300-km altitude orbit about Mercury. An Earth-storable retropropulsion system is used for orbit insertion upon arrival at Mercury. Figure 2-28 compares SEP and ballistic (all-chemical) flight mode performance assuming a Shuttle/Centaur(G') launch in both cases. SEP has generally superior performance in that much shorter flight times are possible for net mass in orbit of 800 kg or better. The SEP power requirement for this mission lies in the range 20 kw < P_0 < 30 kw. Although ballistic flights are possible, a more complex mission profile involving several swingbys of Venus and Mercury is necessary.

Outer Planet Orbiter Missions. Figures 2-29 through 2-32 compare the performance of several different flight modes for achieving orbiters of Jupiter, Saturn, Uranus, and Neptune. The SEP mode always employs an Earth gravity-assist (SEEGA) which is necessary for adequate mass performance with a flat array design; this increases the total flight time compared to direct missions by two years (Jupiter) or three years (Saturn through Neptune). In the case of Jupiter missions, the direct ballistic launch with a Shuttle/Centaur(G') proves quite adequate and can deliver as much as 1500 kg into orbit with a flight time of just over two years. The two indirect modes, ΔVEGA and SEEGA, have comparable performance capability and can deliver much larger payloads into orbit at the expense of much longer flight times. For Saturn missions, the SEP (SEEGA) mode outperforms the all-chemical ΔVEGA mode even when aerocapture (A-C) is employed for Saturn orbit insertion. This continues to be true for Uranus and Neptune orbiter missions, but now the superior performance of NEP becomes evident. Thus, at Uranus, a 1500 kg net mass can be placed into orbit in 8.8 years with NEP, 10.5 years with SEEGA, and 16 years with ΔVEGA. At Neptune, a 1500 kg orbiter requires flight times of 11.3 years with NEP, 12.6 years with SEEGA supplemented by aerocapture, and 15.9 years with SEEGA alone.



MERCURY ORBITER PERFORMANCE COMPARISON

Figure 2-28.



JUPITER ØRBITER PERFØRMANCE CØMPARISØN

Figure 2-29.

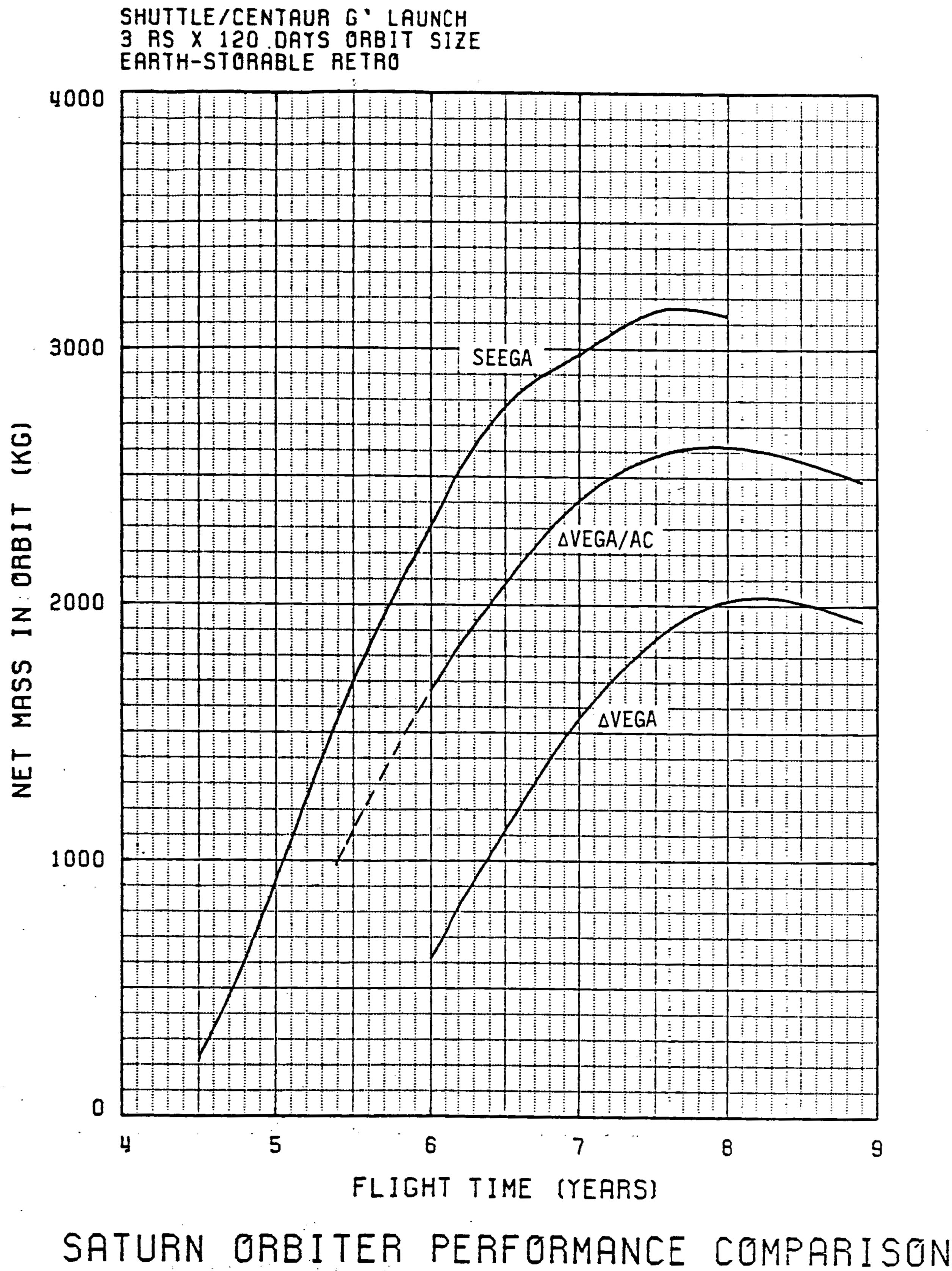
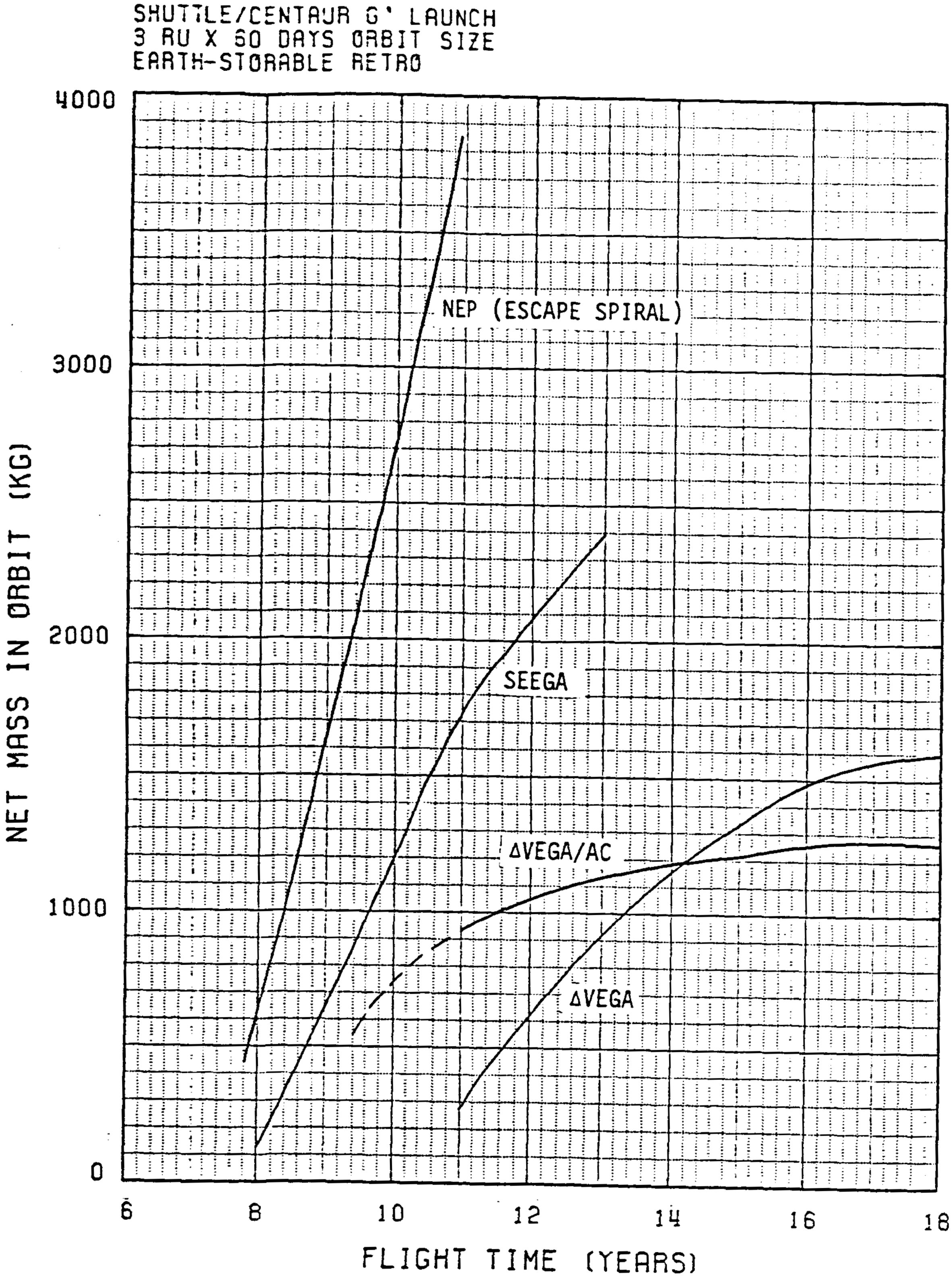
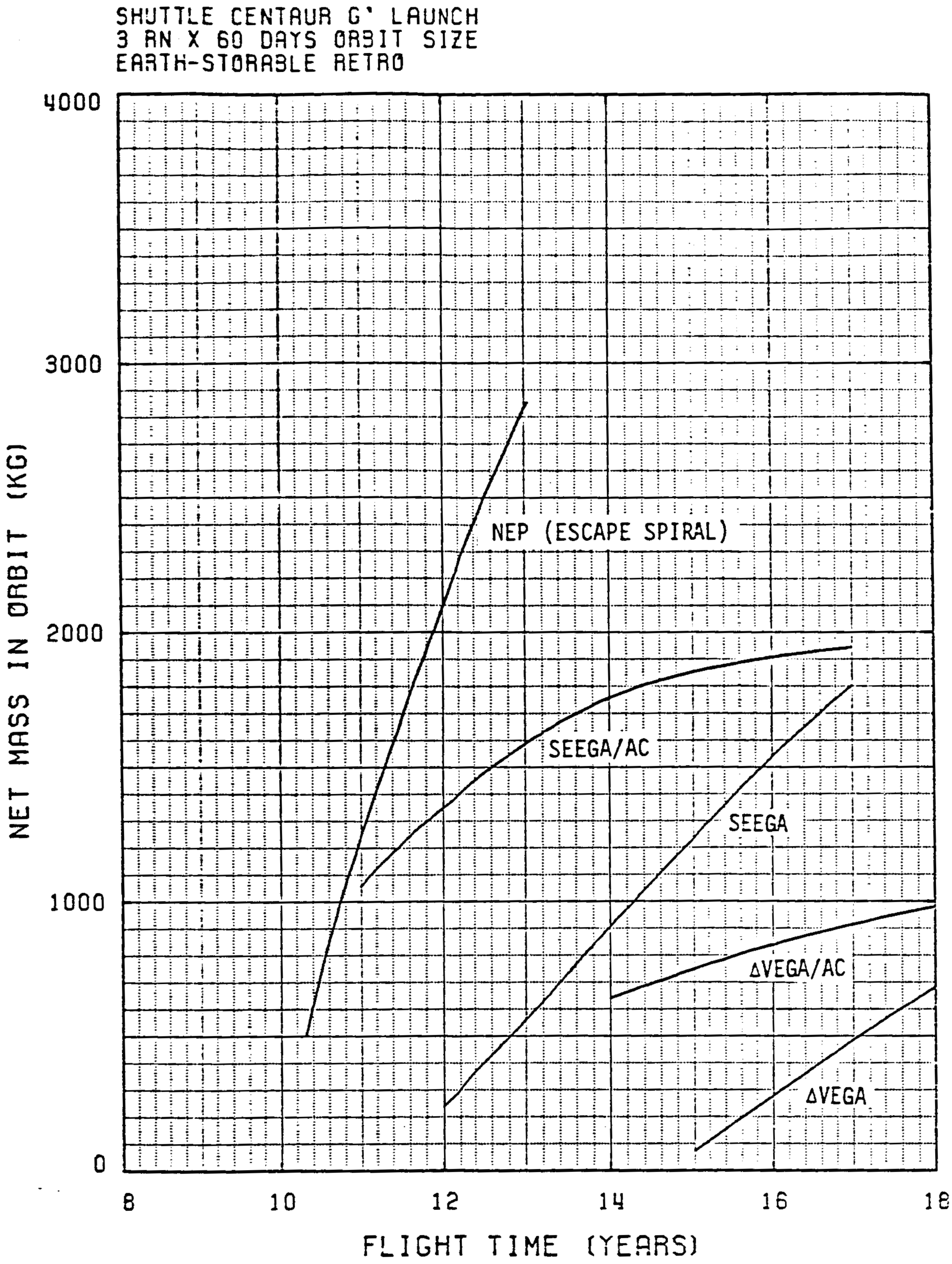

SHUTTLE/CENTAUR G' LAUNCH
3 RS X 120 DAYS ORBIT SIZE
EARTH-STORABLE RETRO
4000
3000
2000
1000
0
NET MASS IN ORBIT (KG)
SEEGA
ΔVEGA/AC
ΔVEGA
4
5
6
7
8
9
FLIGHT TIME (YEARS)
SATURN ORBITER PERFORMANCE COMPARISON

Figure 2-30.



URANUS ORBITER PERFORMANCE COMPARISON

Figure 2-31.



NEPTUNE ORBITER PERFORMANCE COMPARISON

Figure 2-32.

2.7.2 Science Instrument Database

The science instrument database was designed and implemented in order to streamline SAIC's planetary mission studies by reducing the time needed for researching physical and performance data for candidate payload instruments. By providing this information on an automated database, the tedious process of searching through published literature could be eliminated.

The database was also designed to be incorporated into SAIC's mass estimation program. Using the database in this way would allow accurate modeling of the mass and power requirements of a mission by collecting the appropriate instruments to meet the specified science objectives. In the past, mass and power values for the science payload were at times a best guess for the particular mission being studied. By accurately modeling this aspect of mission design, a more accurate cost estimate can also be developed.

The criteria used for selecting instruments to be included in the database are as follows: (1) select only those missions that date back no earlier than 1976; (2) include only unmanned planetary missions; and (3) restrict the lifetime of a particular instrument to 10 years in order to keep pace with advancing technologies. There may be exceptions to criterion (3). For example, the Viking Lander mission may well be retained for a longer period than the designated 10 year limit since there are no lander missions in the planning stages before the year 2000.

The software selected for the database task was DATATRIEVE-11 developed by Digital Equipment Corporation. DATATRIEVE-11 is described as a comprehensive data management tool and was selected because of its compatability with SAIC's resident PDP11/44 computer system. DATATRIEVE-11 is also currently in use on NASA's VAX computer system thus providing compatability with the 11/44.

As of May, 1985 the database contained 119 instruments collected from flyby, orbiter, lander, probe and penetrator missions. By August, 1985, there were 176 instruments, 80 percent of which were compiled from 15 flown and planned missions dating from 1976 and extending to the year 2000 (Table 2-32). These include NASA missions, ESA missions, and joint NASA/ESA missions. The

Table 2-32

Included Missions on Science Instrument Database

MISSION	AGENCY	LAUNCH YEAR	COMMENTS
Viking	NASA	1976	Mars
Voyager	NASA	1977	Outer Planets
Pioneer Venus	NASA	1978	Venus
Galileo	NASA	1986	Jupiter
Giotto	ESA	1985	Comet Halley
Ulysses (ISPM)	ESA	1986	Sun
VRM *	NASA	1988	Venus (PO)
MOM	NASA	1990	Mars (PO)
CRAF	NASA	1991	Comet/Asteroid Flyby
Cassini *	NASA/ESA	1994	Saturn (MMII)
MAO	NASA	1996	Mars (PO)
LGO	NASA	1992	Moon (PO)
NEAR	NASA	1997	Asteroids (PO).
MSP	NASA	2000	Mars (PO)
Ames Mars Penetrator *	NASA/AMES	----	Study only

Total Missions: 15

PO: Planetary Observer

MMII: Mariner Mark II

VRM: Venus Radar Mapper

MOM: Mars Observer Mission (Mars Geoscience/Climatology Observer)

CRAF: Comet Rendezvous/Asteroid Flyby

MAO: Mars Aeronomy Observer

LGO: Lunar Geoscience Observer

NEAR: Near Earth Asteroid Rendezvous

MSP: Mars Surface Probe

ISPM: International Solar Polar Mission

* Entered into database after May 1985

instruments are classified into any one of up to 35 instrument categories (Table 2-33). Each instrument description may use up to 40 fields to define its physical and functional characteristics (Table 2-34), although all 40 fields typically are not utilized. Since information for descriptive fields is still being collected, some categories of an instrument description are blank (see Figure 2-33). As more information is collected, it will be entered into the database where appropriate. The remaining 20 percent of the instruments are proposed or conceptual type instrumentation that could be flown on a variety of missions.

Two software applications were developed once the database was established: (1) the manual payload generator; and (2) the automated payload generator.

Manual Payload Generator. The user designs a single payload by selecting each instrument from the database. After the program is initiated, the instrument categories are displayed on the screen and the user begins the selection process. Once the desired instruments are selected, they are transferred to a file where they can be stored or printed. The tabulated payload includes the instrument name, mass in kg, power in watts, data rate in bps, volume, design base, field of view and pointing accuracy. At the bottom of the list are the total mass and required power for the selected set of instruments (Figure 2-33).

Automated Payload Generator. The automated payload generator develops several different payloads based on the instrument types selected. The restrictive parameters are the maximum allowable mass, power and data rate of the payload to be developed. The user selects the type of mission that is desired (i.e., flyby/rendezvous, orbiter, atmospheric, surface or subsurface). The software collects those instruments that are appropriate to the mission being designed and lists appropriate instrument categories for the user to select from. After the user selects the desired instrument types (i.e., camera, photometer, radar, etc.) the software collects the appropriate instruments and begins combining one instrument from each category into a candidate payload. If the total mass, power and data rate exceeds the specified values,

Table 2-33

Instrument Type Categories

1. Atmosphere Structure Instrument
2. Camera
3. Electron Temperature Probe
4. Gas Chromatograph
5. Interferometer
6. Magnetometer
7. Meteorology
8. Nephelometer
9. Particle Detector
10. Photometer
11. Photopolarimeter
12. Plasma Particle Detector
13. Radar
14. IR Radiometer
15. Net Flux Radiometer
16. Solar Flux Radiometer
17. Retarding Potential Analyzer
18. Seismometer
19. Neutral Mass Spectrometer
20. VIS/IR Spectrometer
21. X-ray Spectrometer
22. Gamma-ray Spectrometer
23. IR Spectrometer
24. Ion Mass Spectrometer
25. UV Spectrometer
26. Water Vapor Spectrometer
27. Cloud Particle Size Spectrometer
28. Specialized Instrument
29. Plasma Wave Instrument
30. Dust Detectors
31. Cosmic Ray Detector
32. Radio Frequency Radiometer
33. Spectrometer
34. Dust Analyzer
35. Radio Receiver

Table 2-34

Descriptive Fields for Instruments

1. Instrument Name
2. Instrument Type
3. Investigation Category
4. Data Collection Mode
5. Weight
6. Power
7. Data Rate
8. Volume
9. Effective Spectrum Region
10. Types of Sensors
11. Ranges
    a. Dynamic
    b. Spectral
    c. Energy
    d. Mass
12. Angular Resolution
13. Field of View
14. Instrument Sensitivity
15. Development Status
16. Principal Investigator/Institute
17. Literature Reference
18. Design Date
19. Instrument Function
20. Design Heritage
21. Mission
22. Sensor Cooling
23. Number of Filters
24. Number of Channels
25. Sample Rate
26. Sample Size
27. Telescope Data
    a. Telescope diameter
    b. Telescope type
    c. F. number
    d. Focal length
28. Bandwidth
29. Pointing Accuracy
30. Pointing Reference
31. Instrument Operating Temperature
32. Mounting location on spacecraft
33. Development Cost
34. Other descriptive information

STRAWMAN PAYLOAD

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Page 1

INSTRUMENT NAME	WT KG	POWER W	DATA RATE BPS	VOLUME CCM	DESIGN BASE	FIELD OF VIEW DEG	POINTING ACCURACY
VISUAL IMAGING SYSTEM	42.1	45.ØØ	2112ØØØ.ØØ	1433Ø.26Ø	VIKING ORBITER	1.54X1.69	
MAGNETOMETER	3	3.ØØ	3ØØ.ØØ	383Ø.ØØØ	LUNAR GEOSCIENCE OBS		
ELECTRIC FIELD DETECTOR	1.5	1.ØØ	128.ØØ		MARS AERONOMY OBS	18Ø SPHER	
SOLAR WIND PLASMA ANAL	4.Ø	5.ØØ	128.ØØ		MARS AERONOMY OBS	15 & 14Ø	
RADAR ALTIMETER	1Ø	18.ØØ	2ØØØ.ØØ	111ØØØ.ØØØ	LUNAR GEOSCIENCE OBS	2	+,-3Ømrad
ELECTRON TEMP PROBE	6	3.ØØ	256.ØØ		MARS AERONOMY OBS	18Ø SPHER	+,-3Ø DEG
GAMMA RAY SPECTROMETER	14	1Ø.ØØ	15ØØ.ØØ	464ØØ.ØØØ	MARS GEOS CLIMAT OBS		5Ø mrad
MAPPING VIS & IR SPECTROMETER	18	12.ØØ	1ØØØØ.ØØ	124ØØØ.ØØØ	MARS GEOS CLIMAT OBS	8XØ.2	9mrad
PRESSURE MODULATED IR RAD	13	15.ØØ	1ØØØ.ØØ	75ØØ.ØØØ	MARS GEOS CLIMAT OBS	Ø.2XØ.7	3mrad
PAYLOAD TOTALS:	111.6Ø	112.ØØ					

Figure 2-33. Payload generated by Manual Payload Generator Program

(Note: Payload represents a hypothetical Inner Planets Orbiter)

the payload is eliminated. If not, it is saved. If too many payloads are developed the user can modify his original mass, power and data rate restrictions and generate a smaller number of candidate payloads. The advantage of this program over the manual payload generator lies in the fact that the computer does all the selection and elimination work on the payloads, thus developing only those payloads that meet, but do not exceed, the mission mass and power restrictions. The generated payloads (Figure 2-34) present the instrument's name, mass, power, data rate, volume and design heritage.

The science instrument database will be constantly modified and updated as new information is collected on the instruments already established in the database and as new mission descriptions become available. It is the intention of SAIC to make the database available to any NASA personnel who wish to use it.

2.8 Earth Science Mission Planning

Major programs undertaken cooperatively by U.S. government agencies are routinely defined through an interagency agreement or memorandum of understanding. NASA and the National Oceanographic and Atmospheric Administration (NOAA) have jointly conducted an ongoing satellite remote sensing program within the purview of an agreement jointly authorized by the two agencies in 1972.

A combination of events, including redirection of agency programs and recently enacted legislative requirements, caused NASA and NOAA to require a revision of the subject agreement. Under contract to NASA, SAIC played a key role in the development and negotiation of the revised "Basic Agreement Between the National Oceanographic and Atmospheric Administration and the National Aeronautics and Space Administration".

SAIC initiated the task to support the revision of the Basic Agreement by recommending a plan of approach to key personnel of both agencies in early January of 1985. Following their concurrence, SAIC outlined the scope and content of the future document, within guidelines from the agencies, and

INSTRUMENT	MASS KG	POWER W	DATA RATE BPS	VOLUME CCM	HERITAGE
SOLID STATE IMAGING	28.00	10.00	100000.00	20000.000	GALILEO ORBITER
MAGNETOMETER	3.20	3.60	300.00	0.000	NEAR EARTH AST REND
ELECTRIC FIELD DETECTOR	1.50	1.00	128.00	0.000	MARS AERONOMY OBS
RADAR MAPPER INSTR	5.70	18.00	54.00	9000.000	PIONEER VENUS ORBIT
VIS & IR MAPPING SPECTROMETER	18.00	12.00	28000.00	126269.000	LUNAR GEOSCIENCE OBS
X-RAY SPECTROMETER	11.00	8.00	1000.00	0.000	NEAR EARTH AST REND
GAMMA RAY SPECTROMETER	12.00	10.00	2000.00	46400.000	LUNAR GEOSCIENCE OBS
ELECTRIC FIELD DETECTOR	0.80	0.70	1.00	600.000	PIONEER VENUS ORBIT
PAYLOAD TOTALS:	84.20	63.30	131483.00		

INSTRUMENT	MASS KG	POWER W	DATA RATE BPS	VOLUME CCM	HERITAGE
SOLID STATE IMAGING	28.00	10.00	100000.00	20000.000	GALILEO ORBITER
MAGNETOMETER	3.20	3.60	300.00	0.000	NEAR EARTH AST REND
GAMMA RAY BURST DET	2.80	1.30	82.00	2400.000	PIONEER VENUS ORBIT
RADAR ALTIMETER	10.00	18.00	2000.00	111000.000	LUNAR GEOSCIENCE OBS
VIS & IR MAPPING SPECTOMETER	16.00	11.00	12000.00	0.000	NEAR EARTH AST REND
X-RAY SPECTROMETER	11.00	8.00	1000.00	0.000	NEAR EARTH AST REND
GAMMA RAY SPECTROMETER	12.00	10.00	2000.00	46400.000	LUNAR GEOSCIENCE OBS
ELECTRIC FIELD DETECTOR	0.80	0.70	1.00	600.000	PIONEER VENUS ORBIT
PAYLOAD TOTALS:	83.80	62.60	117383.00		

INSTRUMENT	MASS KG	POWER W	DATA RATE BPS	VOLUME CCM	HERITAGE
SOLID STATE IMAGING	28.00	10.00	100000.00	20000.000	GALILEO ORBITER
MAGNETOMETER	4.00	3.00	2000.00	2000.000	MARS GEOS CLIMAT OBS
ELECTRIC FIELD DETECTOR	1.50	1.00	128.00	0.000	MARS AERONOMY OBS
RADAR MAPPER INSTR	5.70	18.00	54.00	9000.000	PIONEER VENUS ORBIT
VIS & IR MAPPING SPECTOMETER	16.00	11.00	12000.00	0.000	NEAR EARTH AST REND
X-RAY SPECTROMETER	11.00	8.00	1000.00	0.000	NEAR EARTH AST REND
GAMMA RAY SPECTROMETER	12.00	10.00	2000.00	46400.000	LUNAR GEOSCIENCE OBS
ELECTRIC FIELD DETECTOR	0.80	0.70	1.00	600.000	PIONEER VENUS ORBIT
PAYLOAD TOTALS:	83.00	61.70	117183.00		

INSTRUMENT	MASS KG	POWER W	DATA RATE BPS	VOLUME CCM	HERITAGE
SOLID STATE IMAGING	28.00	10.00	100000.00	20000.000	GALILEO ORBITER
MAGNETOMETER	4.00	3.00	2000.00	2000.000	MARS GEOS CLIMAT OBS
ELECTRIC FIELD DETECTOR	1.50	1.00	128.00	0.000	MARS AERONOMY OBS
RADAR MAPPER INSTR	5.70	18.00	54.00	9000.000	PIONEER VENUS ORBIT
VIS & IR MAPPING SPECTOMETER	16.00	11.00	12000.00	0.000	NEAR EARTH AST REND
X-RAY SPECTROMETER	11.00	8.00	1000.00	0.000	NEAR EARTH AST REND
GAMMA RAY SPECTROMETER	13.00	10.00	2000.00	0.000	NEAR EARTH AST REND
ELECTRIC FIELD DETECTOR	0.80	0.70	1.00	600.000	PIONEER VENUS ORBIT
PAYLOAD TOTALS:	84.00	61.70	117183.00		

Figure 2-34. Payloads Generated by Automated Payload Generator

coordinated working groups composed of NASA and NOAA officials who provided both input and review. SAIC performed analyses of program components to identify potential areas of cooperation and areas where cooperation might be improved. On a broader basis, an appropriate review process was established to ensure that top officials in positions of increasing responsibility were solicited for input and review. As the core of NOAA and NASA mutual program interests lies in the remote sensing of Earth from space, the responsibility for both the preparation and implementation of the revised Basic Agreement lay with the NASA Earth Science Applications Division and the NOAA National Environmental Satellite Data and Information Service. SAIC completed the draft of the revised Basic Agreement at the end of the contract year.

The following is a summary of events prompting the revision, the guidelines set forth by the agencies for SAIC, the procedure followed, and the contents, as well as other related assumptions and implications of the document.

Background. A combination of events prompted NOAA and NASA to revise the interagency basic agreement. These included:

1. A major change in the 1972 Agreement represented by the elimination of the NASA-funded Operational Satellite Improvement Program (OSIP);

2. Directives stated in the Land Remote Sensing Commercialization Act of 1984 that require NOAA and NASA to report on the national status of and develop a plan for remote sensing of the Earth;

3. A mutual interest in interdisciplinary Earth science problems and a concern for the management of a growing volume of Earth and environmental data;

4. Development of the Space Station facility as a national resource;

5. Recommendations from various scientific advisory committees to better define the roles of NOAA and NASA in space-related programs; and

6. An increasing awareness of the potential benefit of joint activity in other program areas.

Guidelines. NASA contracted SAIC to support the negotiation and writing of the revised Agreement with the following guidelines:

1. The Agreement should embrace closer and improved cooperation between NOAA and NASA and encourage the identification of new program areas for cooperation.

2. The Agreement should be an operating plan, providing for the management and coordination of cooperative programs.

3. The Agreement should support the next ten-year period of current and potential cooperative effort.

4. The Agreement should be a practical document, not necessarily expected to cover all eventualities.

5. The first draft of the Agreement should be completed on or before the date when the Earth Science Systems Committee convenes for summer study (1985).

Procedure. The revised Basic Agreement was developed according to the following steps and procedures:

1. The Agreement was structured to include an Umbrella and associated annexes focusing on cooperative activity in a given program area.

2. A kick-off meeting was coordinated by SAIC on January 14, 1985 and attended by designated officials of both agencies who would review and approve the separate parts of the Agreement as they were drafted. These officials represented review levels 1 and 2.

3. SAIC developed drafts of the Agreement parts incorporating and negotiating, when necessary and resolvable, the inputs of said officials and supported the coordination of the level 1 and 2 reviews, an iterative process. Reviewers are listed below:

	NASA	NOAA
Level 1:	Jim Greaves, Code EE Program Manager, Operational Meteorological Satellites	Lisa Shaffer, Chief, International Affairs Unit
	John Theon, Code EE Chief, Atmosphere Dynamics & Radiation Branch	Jennifer Clapp Deputy Chief, External Relations Staff

Jim Dodge, Code EE
Program Science Manager
Mesoscale Processes
Scientific Research

Tony Villasenor, Code EI
Program Manager,
Information Systems Office

Larry Heacock,
Chief, Systems Planning and Development

Harold Yates,
Director, Office of Research and Applications

Russ Koffler,
Director, Office of Satellite Data Processing and Distribution

Greg Hunolt,
Chief, Satellite Services Division

Level 2: Shelby Tilford, Code EE
Director, Earth Science & Applications Division

Ray Arnold, Code EE
Deputy Director, Earth Science & Applications Division

Bill Bishop,
Deputy Assistant Administrator for Satellites of NESDIS

Majorie Courain,
Deputy Assistant Administrator for Information Services of NESDIS

Format and Implicit Use. The format of the Agreement as a document containing an Umbrella and associated annexes serves multiple purposes:

1. The Umbrella sets the tone and basic policies of the Agreement. The annexes, while tied to the Agreement, each provide a relatively independent section focused on a subject area, offering ease of reference and use for those involved in the implementation of cooperative activities for that subject area.

2. New annexes can be added to the Agreement as other program areas are suggested for cooperative activity.

3. The annexes recognize and account for overlap of activities among the cooperative program areas established by such annexes.

4. The format can serve as a template for agreements with other agencies.

The revised Agreement was written in reaction to the mutual interest of NOAA and NASA to establish closer cooperation for the sharing of capabilities and resources in a wide range of program areas. It is intended to guide and direct the various organizational elements within each Agency in its dealings

with the other. Secondarily, the Agreement was written as a means of clarifying the relationship between NOAA and NASA for the benefit of outside groups whose interests and/or programs relate to those of NASA and/or NOAA in some manner. Such groups include the Office of Science and Technology Policy, the Earth Science Systems Committee, the Space Applications Board, and the Space Advisory Committee.

General Assumptions and Provisions. The Agreement was written to incorporate the following basic assumptions and provisions:

1. The Agreement is a practical document that will facilitate closer cooperation between NOAA and NASA for the next ten year period.

2. Each agency is responsible for securing Congressional approval and appropriations for its programs.

3. Participation of other federal agencies is encouraged in the _ad hoc_ working groups established by the Agreement.

4. Joint programs will be conducted on a no-exchange-of-funds basis unless otherwise established case-by-case.

5. NASA-developed advanced technology will be evaluated for possible incorporation in the NOAA operational satellite system. NOAA operational needs will be considered in such development.

6. The Agreement will be signed by the NOAA and NASA Administrators.

7. The responsibility for implementation of joint programs lies with the NASA director of the Earth Science and Applications Division and the appropriate NOAA deputy assistant administrators of NESDIS.

Contents. Summaries of the contents for the four annexes initially established by this Agreement are provided below. It should be pointed out the Annex I largely embodies the cooperative activities relevant to the operational satellite systems addressed in the 1972 agreement. The other annexes enlarge the scope of future interagency cooperation to other program areas.

ANNEX I. OPERATIONAL SATELLITE SYSTEMS

NASA

1. Develops responsible mission requirements and system performance and design specifications.

2. Develops RFP's for construction/maintenance of a satellite system.

3. Designs, engineers, procures, qualifies, and arranges for the launch of operational spacecraft on a reimbursable basis.

4. Provides other support, such as evaluation of sensor calibration and data processing algorithm development, according to agreed terms.

5. Performs modifications on an operational series according to agreed terms.

NOAA

1. Advises NASA of program requirements.

2. Approves NASA-developed mission requirements.

3. Concurs with NASA-developed RFP's.

4. Approves all negotiated contracts prior to awards.

5. Approves budget requirements prepared by NASA.

6. Issues timely reimbursements to NASA.

7. Operates the NOAA CDA stations to control and obtain data from NOAA spacecraft after NASA's check-out.

8. Communicates operational data to NOAA and NASA and others as appropriate.

ANNEX II. ADVANCED SENSOR AND SPACECRAFT DEVELOPMENT

NASA

1. Maintains cognizance of NOAA objectives for space observations of the Earth.

2. Informs NOAA of NASA technology developments.

3. Encourages NOAA participation in NASA advisory groups for the formulation of scientific requirements and performance specifications for experimental sensors and spacecraft.

4. Encourages NOAA participation on NASA science teams during pre-flight development and post-launch performance evaluation, including calibration.

5. Determines and performs modifications required to make a NASA experimental system operational for NOAA objectives.

6. Develops transition plan for the transfer of designated NASA experimental systems to NOAA operations.

7. Develops advanced sensors and spacecraft and provides other support for NOAA as requested and on a reimbursable basis.

8. Provides experimental data to NOAA.

9. Encourages NOAA participation in Space Station planning.

10. Provides space on NASA spacecraft for NOAA sensors as available.

NOAA

1. Maintains cognizance of NASA technology developments.

2. Informs NASA of NOAA program objectives for the development of advanced systems.

3. Determines the applicability of a NASA experimental system for NOAA operational use.

4. Approves NASA transition plan for the transfer of experimental systems to NOAA.

5. Requests NASA support and reaches agreement on NASA plans to develop advanced sensors and spacecraft required by NOAA or of mutual interest to both agencies, providing reimbursement as agreed.

6. Provides space on NOAA spacecraft for NASA experimental sensors as available.

7. Provides NOAA support facilities to NASA as requested for the pre-flight development and in-flight operation and performance evaluation of a new sensor or spacecraft.

ANNEX III. EARTH SCIENCE RESEARCH

NASA

1. Requests NOAA participation on planning and advisory groups for NASA science programs.

2. Involves NOAA scientists in the peer evaluation of proposals submitted to NASA research programs.

3. Encourages NOAA participation in NASA research and investigations, including the development and validation of Earth science models and satellite image processing and analyses.

4. Provides support facilities such as aircraft and data processing for NOAA research and applications programs according to agreed terms.

5. Provides results of NASA research programs to NOAA according to agreed terms.

6. Conducts applications research in cooperation with NOAA and provides assistance in the transfer of such results and techniques to NOAA data and information centers and laboratories.

7. Participates jointly with NOAA in national and international science programs to promote interdisciplinary research in Earth science and environmental monitoring.

<u>NOAA</u>

1. Involves NASA scientists in peer evaluation of proposals submitted to NOAA research programs.

2. Participates in NASA Earth science investigations through submission of proposals to NASA programs.

3. Provides support facilities such as aircraft and data processing for NASA research programs according to agreed terms.

4. Provides data acquired by NOAA space-based and ground-based systems for use in NASA research programs.

5. Conducts applications research in cooperation with NASA.

6. Participates jointly with NASA in national and international science programs to promote interdisciplinary research and applications in Earth science and environmental monitoring.

ANNEX IV. DATA MANAGEMENT

<u>NASA</u>

1. Designates a point of contact to whom NOAA special requests for NASA experimental data shall be directed and through whom NASA special requests for NOAA operational data shall be placed.

2. Provides to NOAA experimental remote sensing data sets and value-added and derived products appropriately validated and documented, subject to federal redistribution policy.

3. Sustains membership in the NOAA/National Environmental Data Referral Service.

4. Provides NOAA access to NASA experimental data management systems.

5. Coordinates with NOAA in the development of data catalogs and directories to facilitate universal access.

6. Makes available NASA communication links for transfer of NOAA data in support of NASA research programs.

7. Encourages NOAA participation in the planning, definition, development, and evaluation of NASA science data management and processing systems.

8. Provides NOAA with NASA research results on data quality and improved calibration techniques.

9. Supports transfer to NOAA of design concepts and system requirements resulting from the development of NASA pilot data systems.

NOAA

1. Designates point of contact to whom NASA special requests for NOAA operational data shall be directed and through whom NOAA special requests for NASA experimental data shall be placed.

2. Provides NASA with scientists and program managers with NOAA ground and space-based, real-time and retrospective data as requested and on a preferred user basis.

3. Supports NASA membership in the NOAA/National Environmental Data Referral Service.

4. Coordinates with NASA in the development of data catalogs and directories to facilitate universal access.

5. Reprocesses operational data sets for use in NASA research programs, incorporating improved calibration and geometric correction parameters provided by NASA, according to agreed terms.

6. Notifies NASA of intent to eliminate any NESDIS environmental data sets and honors NASA requests to save data sets of interest to NASA.

SAIC successfully met the contract requirement to provide a draft of the revised NOAA-NASA Basic Agreement to Code EE. The document has been reviewed by all NASA and NOAA offices through the formal NASA and NOAA approval procedure. It has been favorably reviewed by NASA advisory groups, as well, and is being prepared for signature by the administrators of both agencies.

2.9 Planetary Data System Planning

SAIC has supported the Solar System Exploration Division in the continued planning and development of a computerized system for planetary science data to be used by the NASA-sponsored planetary science community. In carrying out this task, SAIC staff have played a significant role in the design of a data system to serve a broad community of planetary scientists located at universities and institutions across the U.S. and abroad. During the contract year, SAIC provided the technical expertise and coordination to develop the operational concept for a planetary data system and supported the publication of two documents which provided advisory guidelines from the planetary community for the system concept and implementation. The following summary describes the events significant in the planning of the system and with which SAIC was closely involved.

Concept. The concept of a Planetary Data System (PDS) originated during a three-day workshop hosted by the Solar System Exploration Division (Code EL) and the newly formed Planetary Science Data Steering Group (PSDSG). The PDS concept, originally called Planetary Science Support and Analysis Subsystem (PSSAS), embraced the collection, archiving, management (catalogs, database management systems, documentation), and distribution of all data obtained by planetary spacecraft, both in the past and for future missions.

Three major tasks were to be performed by SAIC in support of the planetary data effort. These were: (1) editing and publishing the proceedings of the workshop, as well as writing a Summary Document; (2) extracting from the proceedings the system definition and a plan for the implementation of the PDS, sufficient in detail to support a request for funding; and (3) providing the executive secretary to the PSDSG and performing

various other liaison and advisory activities for Code EL, especially interacting with the planetary community, the pilot data system efforts of the Information Systems Office of NASA Headquarters (Code EI), and appropriate technical activities elsewhere in NASA and industry.

Workshop chairpersons and PSDSG members worked closely with SAIC personnel to ensure that the concerns and opinions expressed by the planetary scientists at the workshop were validly represented. The workshop summary document was allowed to reflect the desired capabilities for the PDS, without the framework of fiscal constraints, and the dissatisfaction of the community with currently practiced data management procedures. The document received wide acceptance across NASA for defining a data management system in adherence with directives from the Committee on Data Management, Access, and Communications (CODMAC), a group external to NASA which was formed to voice the needs of persons working in the science and technology fields for improved data management.

Continued Activities. The concept of the PDS was both unique and highly sophisticated in its proposed capability to manage data and support the high level of query and correlative analysis required by the planetary community. An experimental system was to be planned and implemented as an operational system with cost and functional guarantees. A commitment of NASA resources for the development and operation of the PDS required the preparation of an acceptable plan, on which SAIC, in coordination with the planetary community, focused its efforts.

A timeline was developed which supported the management of data acquired by the Galileo mission and the first of the Mariner Mark II and Surveyor missions. Realistic budget estimates indicated limited initial funding with growth to support development later on. Appropriate technologies continue to emerge at an astounding rate and at a lower cost. All indications were for the development of a core system which could provide a minimum set of requirements and grow to support Discipline Centers and on-line correlative data analysis capabilities. The PSDSG endorsed this implementation concept and offered to participate in the generation of a Concept Document and Implementation Plan.

Liaison and coordination with other data management efforts, especially those also dealing with planetary data, were supported by SAIC. The Pilot Planetary Data System (PPDS) is exploring many of the technologies necessary to implement the PDS. The NASA National Space Science Data Center (NSSDC) is the designated repository for all space data and as such plays a part in the distribution of planetary science data. SAIC also monitored the progress of the other NASA pilot data system developments.

The National Academy of Sciences Committee on Data Management and Computation (CODMAC) advises NASA on the adequacy of their data management programs. The Workshop Proceedings and a discussion of implementation strategies for PDS were presented by SAIC personnel to the CODMAC in January.

The PSDSG has advisory responsibility to Codes EL and EI regarding planetary data issues and represents the planetary community to NASA Headquarters on similar concerns and issues. The primary concerns of the PSDSG relate to utilization of the Low Rate Processor (LRP) and the Multi-mission Image Processing Laboratory (MIPL) at JPL, the coordination of PPDS and PDS, and the objectives of the NSSDC for data management and distribution.

SAIC monitored those data management technologies and developments of immediate use to the developing PDS. These included: data standards, optical storage, communication (especially modem-supported networks and the NASA SPAN network), database management systems, and self-documenting data definition languages. In addition, SAIC personnel represented the PDS position at the Division of Planetary Sciences (DPS) meeting in Hawaii in November, 1984.

Administrative Support and Services. Within this task area, SAIC staff provided both technical and administrative support to Code EL for program office operations during the contract year. This support included:

1. Routine assistance in operation of office hardware and software, including maintenance of customized applications;
2. Design and implementation of customized applications, including equipment tracking database, travel database, and contract tracking and review databases;

3. Assistance for RTOP Review including preparing statistical summaries of the planetary science programs for program managers; and

4. Consultation and assistance in the development of equipment procurements.

2.10 Graphics Support

The purpose of this task area is to provide a special ODC (Other Direct Costs) resource to NASA Headquarters - Code EL for the preparation of view-graphs, slides, and hard copy handout material. This work is performed by the Art/Graphics group of SAIC located in McLean, VA. The graphics products include both color (multi-image) and black-and-white formats of high quality that satisfy Code EL's needs for consistent, visually appealing presentations of their program in the areas of advanced studies, planning, project status, and new start proposals. Typical of such presentations are those made to the Space Science Board, Space Club, and Congressional committees. Numerous job orders have been fulfilled during the past contract period.

2.11 Conference Support

The Director of the Solar System Exploration Division, at the conclusion of the Solar System Exploration Committee (SSEC) activities, established the Solar System Exploration Management Council (SSEMC). The Council meets with the Director and his staff three times per year in a review and advisory role. The membership consists of approximately 20 program participants from NASA Centers, JPL, Universities, and private industry who are regarded as spokes-persons for the broader community of scientists and engineers active in NASA's planetary exploration activities.

These activities include comprehensive programs of flight mission developments, mission operations, data analysis, and support research. An overall strategy for the next 15 years has been recommended by the NASA Advisory Council's Solar System Exploration Committee which covers all of these areas. The function of the SSEMC is to assist the Director of the Solar

System Exploration Division in the detailed implementation of this strategy, a strategy which, by its long-term nature, must be an evolving strategy that takes into account developments elsewhere in the Agency, as well as continued progress in the planetary sciences.

The Management Council provides assessments pertaining to:

1. Reviewing the progress of missions in their study and in their development phases;
2. Establishing priorities among ongoing and proposed future activities of the Division;
3. Identifying approaches that will reduce the cost of, or maximize the efficiency of, missions to explore the solar system;
4. Examining the content of, and means of implementing, research needed to support ongoing and future solar system exploration; and
5. Determining technology requirements and capabilities in support of planetary exploration.

The Advanced Studies Team at SAIC have provided two areas of support to the SSEMC activity: (1) conference administrative support; and (2) council participation. All of the SSEMC meetings are arranged and conducted under the guidance of SAIC conference specialists. This support includes site preparations, travel arrangements, direct meeting support (word processing, documentation, special events, etc.) and expense reimbursements for non-NASA participants. Council participation includes direct involvement of John Niehoff, Manager of SAIC's Space Sciences Department, as a council member. It also includes special technical study efforts requested by the Council in support of its review and advisory role. SAIC has provided these areas of support to four council meetings. It is anticipated that the scheduled frequency of SSEMC meetings, and the support being provided by SAIC, will continue for the foreseeable future.

3. REPORTS AND PUBLICATIONS

Science Applications International Corporation is required, as part of its Advanced Mission and Information Studies contract with the Solar System Exploration Division (Code EL), to document the results of its analyses. This documentation typically appears in one of two forms. First, reports and/or presentations are prepared for each scheduled contract task. Second, publications such as conference papers and journal articles are prepared by individual staff members on subjects related to contract tasks which are considered to be of interest to the aerospace community. A bibliography of the reports and publications completed (or in preparation) concerning work performed during the contract period 1 June 1984 through 31 May 1985 is given below. These documents are available to interested readers upon request.

3.1 Task Reports for NASA Contract NASW-3622

1. "Advanced Mission Studies Tenth Annual Report", Study No. 1-120-340-A10 (SAIC-85/1118), May 1984.

2. "Aerobraking/Aerocapture Capabilities Review", Study No. 1-120-340-S17 (SAIC-84/1146), July 1984.

3. "Trends in Planetary Data Analysis - Executive Summary of the Planetary Data Workshop", N. Evans (SAIC), ed., NASA Conference Publication 2333, 1984.

4. "Planetary Data Workshop", N. Evans (SAIC), ed., NASA Conference Publication 2343, 1984.

5. "An Algorithm for Estimating Annual Funding Levels for Planetary Exploration Development Projects", Study No. 1-120-340-C12 (SAIC-84/1845), December 1984.

6. "Science Instrument Database", Study No. 1-120-340-S18 (SAIC-85/1726), May 1985.

7. "Planetary Missions Performance Handbook, Volume I (4th Edition) -- Outer Planets", SAIC, in preparation.

8. "Advanced Mission Concepts for Outer Planets Exploration", SAIC, in preparation.

3.2 Related Publications

Butera, M. K., "A Correlation and Regression Analysis of Percent Canopy Closure vs. TMS Spectral Response for Selected Forest Sites in the San Juan National Forest, Colorado", Digest: 1985 International Geoscience and Remote Sensing Symposium (IGARSS '85), Vol. 2, IEEE Contract No. 85CM2162-6, 1985.

Butera, M. K., "Remote Sensing of Coastal Wetlands: Where is Research Headed", Proceedings of a Working Group: Meeting on Integration of Remote Sensed Data in Geographic Information Systems for Processing of Global Resource Information, Washington, DC, Cerma International Conf. Series, May 1985.

Feingold, H., "Comet Nucleus Sample Return", Journal of the British Interplanetary Society, Vol. 37, No. 8, August 1984.

Feingold, H., Hoffman, S. J. and Soldner, J. K., "A Comet Nucleus Sample Return Mission", Paper No. AIAA-84-2027, AIAA/AAS Astrodynamics Conference, Seattle, WA, August 1984.

Friedlander, A. L., "Titan Buoyant Station", Journal of the British Interplanetary Society, Vol. 37, No. 8, August 1984.

Friedlander, A. L., and Soldner, J. K., "Meteoroid Capture into Earth Orbit by Atmospheric Drag", Paper No. AIAA-84-2055, AIAA/AAS Astrodynamics Conference, Seattle, WA, August 1984.

Hoffman, S. J., "A Comparison of Aerobraking and Aerocapture Vehicles for Interplanetary Missions", Paper No. AIAA-84-2057, AIAA/AAS Astrodynamics Conference, Seattle, WA, August 1984.